UNCLASSIFIED

AD 296 401

Reproduced
by the

ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA

Interim Report No. 1

of the

VARIABLE-SPEED RECORDER-REPRODUCER

First Quarterly Progress Report, 5 May 1962 to 5 November 1962

to

U. S. Army Signal Research and Development Laboratory
U. S. Army Signal Supply Agency
Fort Monmouth Procurement Office
Fort Monmouth, New Jersey

In response to Contract No. DA 36-039 SC-89067

RR 1733

27 November 1962

American Scientific Corporation
(formerly Reed Research, Inc.)
900 Slaters Lane
Alexandria, Virginia

Interim Report No. 1

on the

VARIABLE-SPEED RECORDER-REPRODUCER

to

U. S. Army Signal Supply Agency
Fort Monmouth Procurement Office

In response to Contract No. DA 36-039 SC-89067

First Quarterly Progress Report, 5 May 1962 to 5 November 1962

"QUALIFIED REQUESTORS MAY OBTAIN COPIES OF THIS REPORT
FROM ASTIA. ASTIA RELEASE TO OTS NOT AUTHORIZED"

The object of this project is to design and construct an engineering
test model of a rack mounted, audio recorder-reproducer using a
plastic base oxide coated tape and capable of operation at selectable
variable tape speeds.

Prepared by

Thomas Lanyi
Donald E. Reed

TABLE OF CONTENT

TABLE OF CONTENT
(continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(continued)

LIST OF ILLUSTRATIONS
(continued)

LIST OF TABLES

PURPOSE

The purpose of this contract is to design and construct an engineering test model of a rack mounted, audio recorder-reproducer using a plastic base oxide coated tape and capable of operation at selectable variable tape speeds. This recorder-reproducer should be able to operate repeatedly and continuously, requiring only replacement of recording media when necessary. The recorder-reproducer should accept two signals for simultaneous dual track recording and playback.

The above work was proposed to be carried out in six phases.

The first phase (Design and Preliminary Procurement) is completed.

The second phase, prototype construction is almost completed and overlapping with this phase the third phase, prototype test and final design is being carried out.

ABSTRACT

The report describes the basic design consideration for this record-reproducer stemming from the peculiarities of contract requirement. Deviations from conventional magnetic recording are described and the necessities of these changes are proved. The unorthodox tape transport system is an evolution from a conventional drive mechanism through the experience gained from Reed's K-3 Variable-speed Magnetic Tape Transcriber to the specifications of this contract.

Design and construction changes are described for changes from one-channel operation to a dual-channel system.

BACKGROUND STUDY

The contract calls for a design of a recorder-reproducer with continuously variable speed that is able to operate repeatedly and continuously, requiring only replacement of the recording media when necessary. To comply with the requirements of the contract an extensive study of the today's state-of-the-art was made.

An appreciation of tape recorder problems, principles and practices is not a matter of mere academic interest. There are very practical advantages to such knowledge. Many hundred different and excellent designs have appeared over the years, and it is not necessary to start from scratch and work the whole thing out from first principles. Nevertheless, unless the general principles are understood and applied, the problem will only be solved, if ever, by trying out circuit after circuit until the desired performance has been secured.

A tape recorder consist of two basic parts: mechanical (the transport mechanism), and electronic.

It is difficult to draw a clear physical line between the electronic part and the transport. Certain electronic elements are often mounted on the transport so that electronic and mechanical functions may be controlled simultaneously or for some other reason. This report will be divided in two: In the first part the electrical design

- 1 -

will be discussed; the second part will describe the mechanical design aspects.

To avoid possible misunderstanding the following terms should be clarified: The terms record, reproduce (playback) amplifier will appear frequently; these do not include the audio power amplifier. On the other hand the preamplifier is an integral part of the amplifier, it will not be considered as a separate unit. The term amplifier will be understood to include preamplifier.

Before starting with the power amplifier design considerations, two basic decisions were made:

(1)   Since the temperature requirement covers a fairly wide range it was decided that a vacuum tube circuit design will be used.

(2)   In the power supply metallic rectifiers will be used, and the power supply will be on the same chassis with the audio amplifiers.

Power Amplifier Design Considerations

The audio power amplifier converts a signal voltage, generally obtained from a voltage amplifier into an output of sufficient level for driving a transducer, such as a loudspeaker.

The important requirements for audio amplifiers are:

(a)   The amplifier should be capable of passing the full range of audio frequencies without discriminations or alterations.

(b)   The amplifier should operate equally throughout a wide range of amplitudes.

(c)   The output wave form must be as nearly as possible an undistorted reproduction of the original.

(d)   The amplifier gain must conform to a given set of conditions in terms of the desired amount of output power to be delivered from the available input voltage.

(e)   Noise and hum must be absolutely minimum.

(f)   Input and output impedances must be designed to match those of the devices immediately preceding and following the amplifier equipment.

For the audio power output stage two beam power amplifier tubes were chosen for use in a push-pull configuration. These two tubes were connected as tetrodes, and the bias conditions were set for Class AB_1 operation. Cathode bias was selected to reduce the number of components.

The two tubes in a push-pull power output stage requires input signal voltages of equal magnitude but of opposite phase. The signal voltages driving the push-pull stage must be symmetrical with respect to ground. This is performed by the phase inverter section of the amplifier.

The purpose of this section is:

- 3 -

(a)   to provide a balanced drive signal for the grids of the

output tubes from a single ended input and,

(b)   to provide enough swing of this balanced output to drive

the output tubes to full power.

This swing is the function not only of the tube characteristics,

but the B plus voltage available for its plate circuit.

The balance of the inverter circuit depends upon the individual

tube parameters.

Two types of phase inverters were considered: First was the

cathode coupled phase inverter such as shown in Figure 2. In the

cathode coupled phase inverter stage the second grid is connected to

AC ground. The advantage of this arrangement is that the capacitor

from the second grid to ground can be made much larger than would be

normal practice for a coupling capacitor. Being at ground potential it

will not introduce additional stray capacitances, thereby will not affect

the high frequency response.

Second type of phase inverter was the split load phase inverter.

Here half of the plate load is connected between the plate and B-plus

while the other half is connected between the cathode and ground. The

disadvantage of this phase inverter circuit is that its output is restricted

because the load is split. On the other hand the stability of balance with

tube parameter variations is excellent.

Three different types of power amplifier as shown in Figure 1, 2 and 3 were designed and the breadboard model of each was built.

The first such design is shown in Figure 1. This is push-pull output stage using two 6AQ5 beam power amplifier with cathode biasing. A Stancor A-3872 audio output transformer (18 watt maximum) was used, a single stage split load phase inverter driven by a triode amplifier stage preceded the output stage. Three other R-C coupled audio amplifier stages completed the power amplifier design. This design did not have enough gain, had poor high-frequency response and did not give the required eight-watt undistorted output.

The next audio amplifier design is shown in Figure 2. Here the same output stage was used with a cathode coupled phase inverter. Special care was taken that the coupling capacitors grid resistors and the phase inverter plate-load resistors were closely matched. The slightly higher values were included in the circuit associated with that half of the phase inverter which was direct coupled to the plate of the first stage.

This design still does not have the required eight watt undistorted output. The main difficulty came from the audio output transformer.

The only available audio output transformer at that time, which complied with the contract specifications was the Chicago Transformer Company's BOH-9 output transformer. This transformer is designed
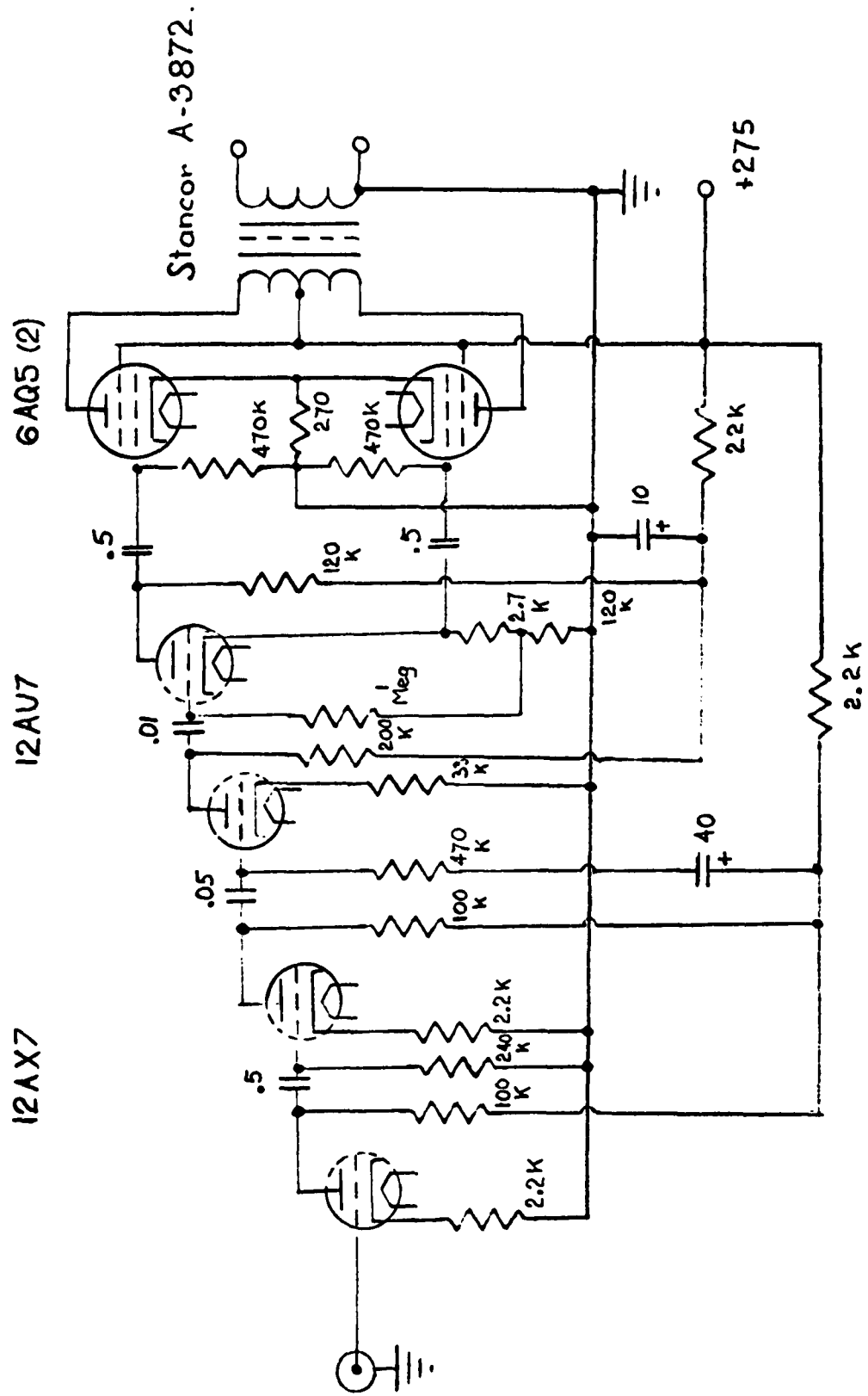
FIGURE 1

Audio Amplifier and Power Amplifier (first-breadboard model)
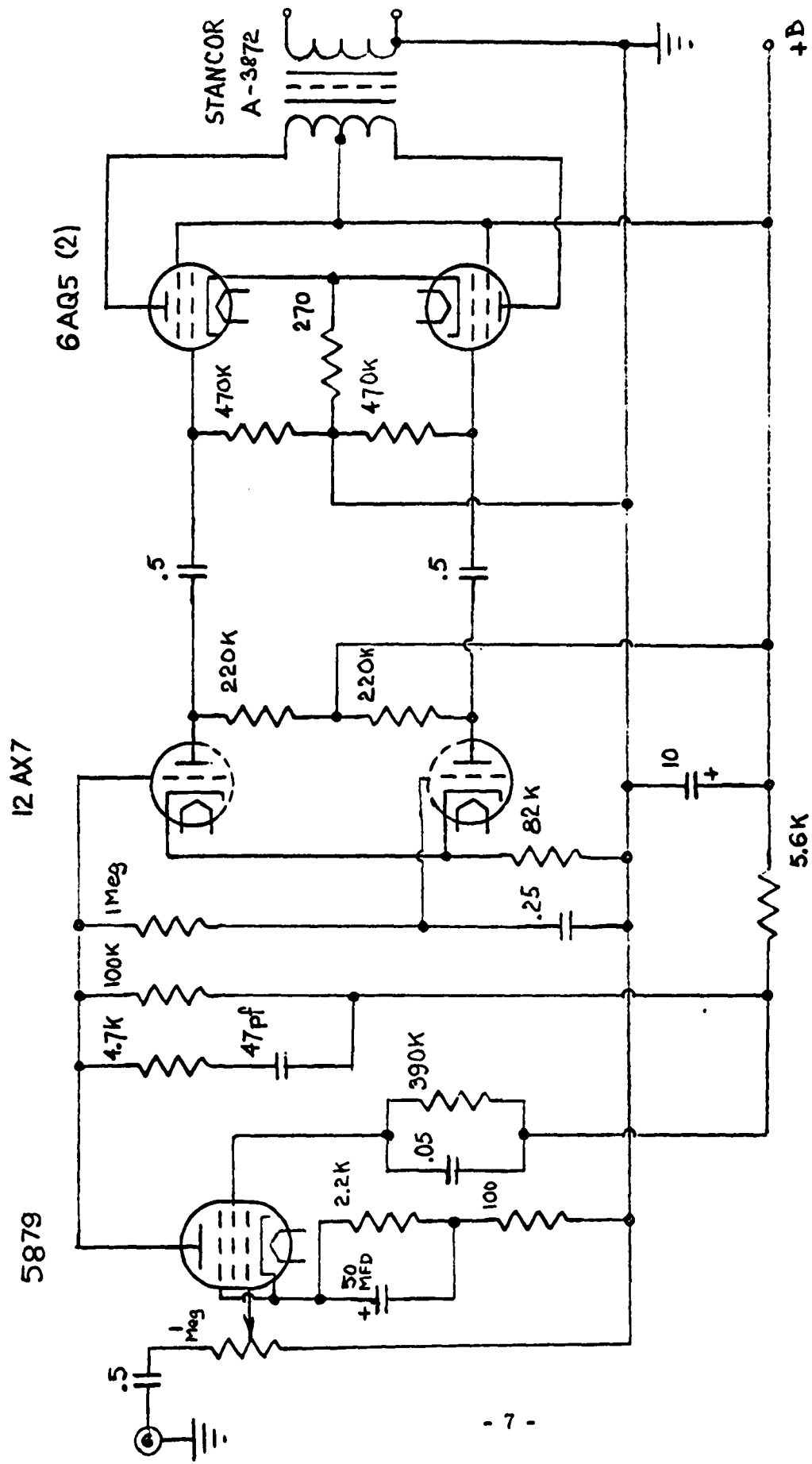
FIGURE 2

Audio Amplifier and Power Amplifier (second-test model)

- 7 -

and built in accordance with MIL-T-27A. Utilizing this transformer we redesigned the power amplifier as shown in Figure 3. Here, two R-C coupled triode audio amplifiers feed the signal to a direct·coupled amplifier stage to a split load phase inverter; this in turn, swings the two 6L6 beam power amplifier tubes in tetrode connection. The output is a Class AB_1 push-pull output with a cathode bias. This design with the audio output transformer previously mentioned, was able to supply the undistorted eight-watt signal.

Amplifier Design Considerations

An audio amplifier is one, "which is designed to amplify audio frequencies in the form of feeble voltages up to the point where they can be reconverted into useable amounts of acoustical power." The important requirements for the audio amplifier are the same as was described for the power amplifier.

Two generalized forms of amplifiers are used in magnetic recording. The classification of each form is functionally determined:

A recording amplifier essentially couples the input device to the recording head; this amplifier merely transfers the signal with amplification from the input device to the recording head.

A reproduce (playback) amplifier is essentially similar to the recording amplifier, and couples the reproduce (playback) head to the output device.
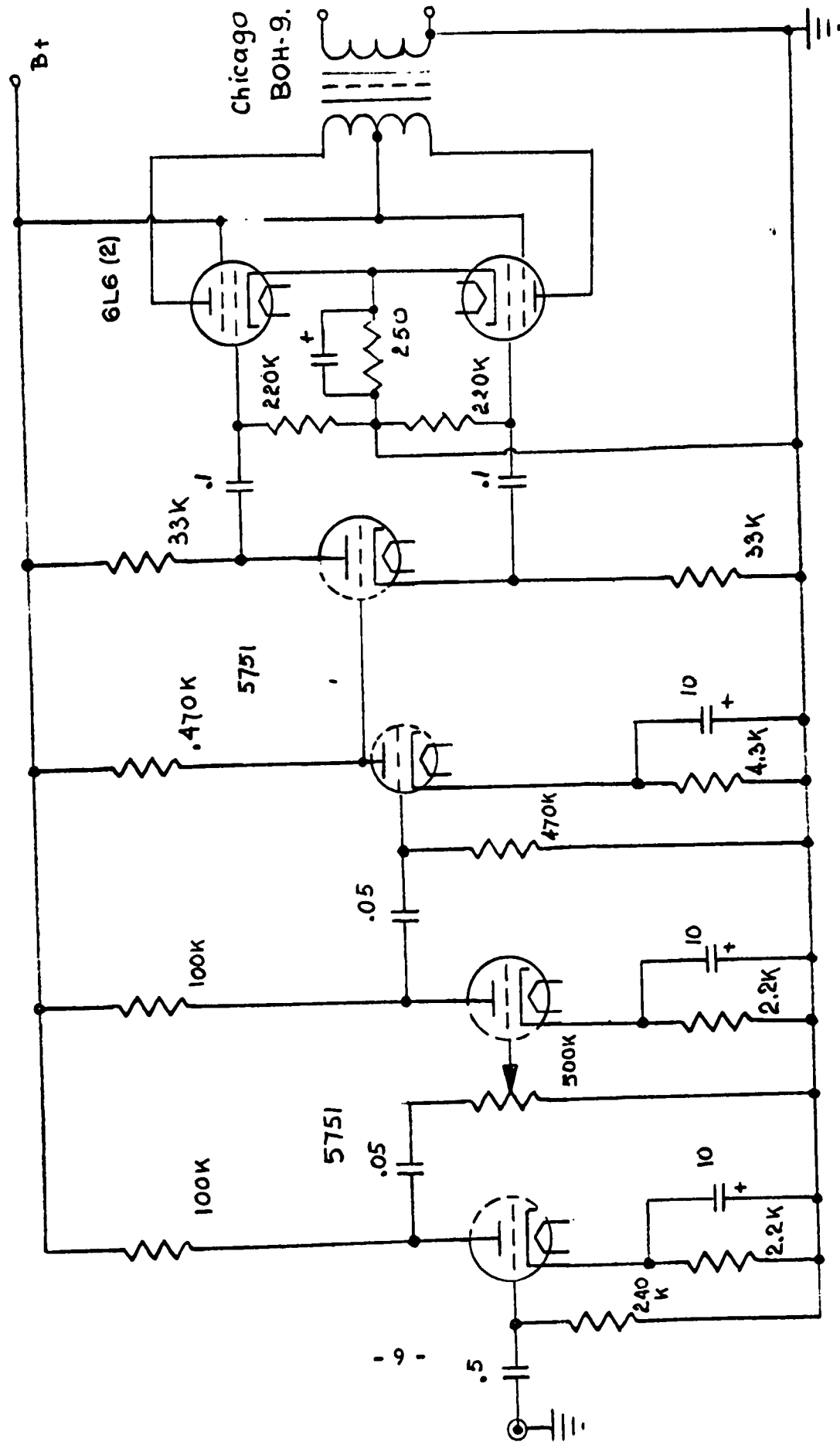
FIGURE 3

Audio Amplifier and Power Amplifier (third-test model)

- 9 -

Collectively both amplifiers interconnect the input and output of the complete recording playback system. These two forms of amplifier will be elaborated later in detail. At this point, we are discussing audio amplifiers in general.

Preamplifier, as it was mentioned previously is considered as part of an audio amplifier. It is a voltage amplifier used in front of a high-gain audio amplifier to raise the input level of a transducer to the input level of the audio amplifier, i.e., the output of the preamplifier feeds one or more successive voltage amplifiers until the input signal has been sufficiently amplified to a level where it can drive a loud-speaker or activate a magnetic recording head.

The preamplifier has to perform the following functions:

(a)   Amplify the low output of the sources or transducers to a level high enough to drive the audio amplifier.

(b)   Switch various input sources.

(c) .   Produce modification of frequency response to compensate for losses in recording.

(d)   Equalize for various fidelity losses (speed, etc.)

(e)   Reduce and/or eliminate noises.

From the input sensitivity and input impedance requirement, we can draw the conclusion what kind of a preamplifier should be designed.

Since floating and balanced inputs are required an audio input transformer must be used.

To achieve the preceding requirements it is contemplated to design a three tube (double triodes) preamplifier for high and low level input as shown in Figure 4. Triodes have been chosen to get better gain-to-noise ratio. To eliminate A-C heater-to-cathode leakage (hum) filtered D-C voltage was used for the filament supply.

Here the low level signal is fed into a 5751 double triode which is an R-C coupled audio amplifier. From the first triode the signal is fed through a .022 ufd condenser and a 1-megohm series resistor bypassed by a 4.7 pf condenser. The necessary equalization circuit can be inserted at this point. This two-stage audio frequency amplifier is connected through a 47K ohm series resistor and a 0.1 ufd coupling condenser to the high-level input. The input level at this point is controlled by a 500K ohm potentiometer.

The high-level signal can be fed into a 1/2 - 5814 double triode tube with the necessary switching arrangement. This first stage is a cathode follower stage. Two more R-C coupled audio amplifier stages follow the cathode follower using 5751 double triode tubes. Other compensating circuits (tone controls) can be inserted here between these two stages. The output stage is the other half of the 5814 tube that was used as cathode follower. This output stage is a
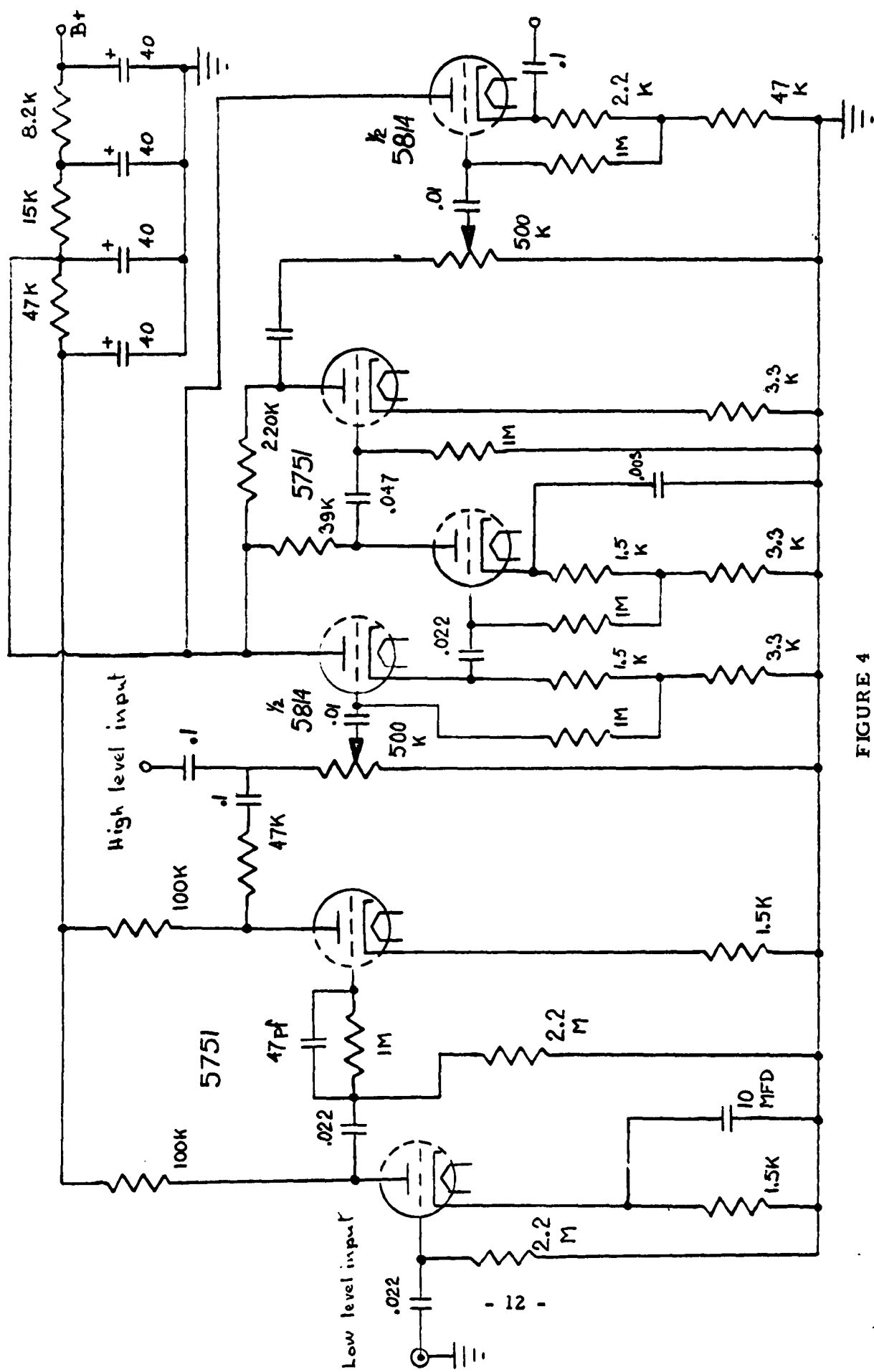
FIGURE 4

Record Amplifier (Breadboard model)

- 12 -

cathode follower again for which the load impedance is 200K ohm (or higher) shunted by .007 ufd or less.

Plate power supply voltage for this amplifier is obtained from the output of a three section R-C filter. This filter will provide a maximum rejection of very low frequencies as well as a reduction in 60 and 120-cycle ripple.

The breadboard model of this amplifier was built and tested. The test was conducted in such manner that special attention was given to the following factors:

1.   gain

2.   tube noise, component noise

3.   hum

4.   microphonics and distortion

The amplifier as shown in Figure 4, had 1-millivolt sensitivity without using the audio input transformer and without any insertion loss caused by equalization. From the test it seemed that the sensitivity was not high enough without inserting a high-gain pentode stage in front of the low-level input. The over-all frequency response was not satisfactory: the high frequency end of the audio spectrum was half of the mid and low frequency range. From the test it seemed that the design had inherent difficulties that would take more time to eliminate than to choose a different approach and make a new design.

- 13 -

Before going into the design of the new amplifier, the power amplifier was modified as shown in Figure 5. Two 6L6 beam power amplifier output tubes were connected to the BOH-9 audio output transformer. The tubes were used as tetrodes in push-pull connection, Class AB_1 amplifiers with fixed bias. Frequency measurement at 15-watt output is tabulated in TABLE 1, and the measurement result is shown in Figure 6. The results of harmonic distortion measurements are tabulated in TABLE 2 and are shown also on Figure 6. These measurements were only exploratory tests to find values for the design of the amplifier. Both test were made with the Heathkit Audio Analyzer.

TABLE 1

Frequency response at 15-watt output

	20 cps	40 cps	100 cps	1 kc	5 kc	10 kc	15 kc	20 kc	30 kc
db	-1.7	-0.6	-0.5	0	0	0	0	0	0

FIGURE 5

Power Amplifier (modified)

FREQUENCY IN CYCLES PER SECOND
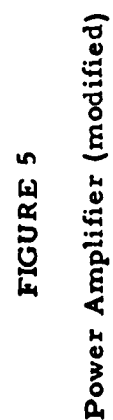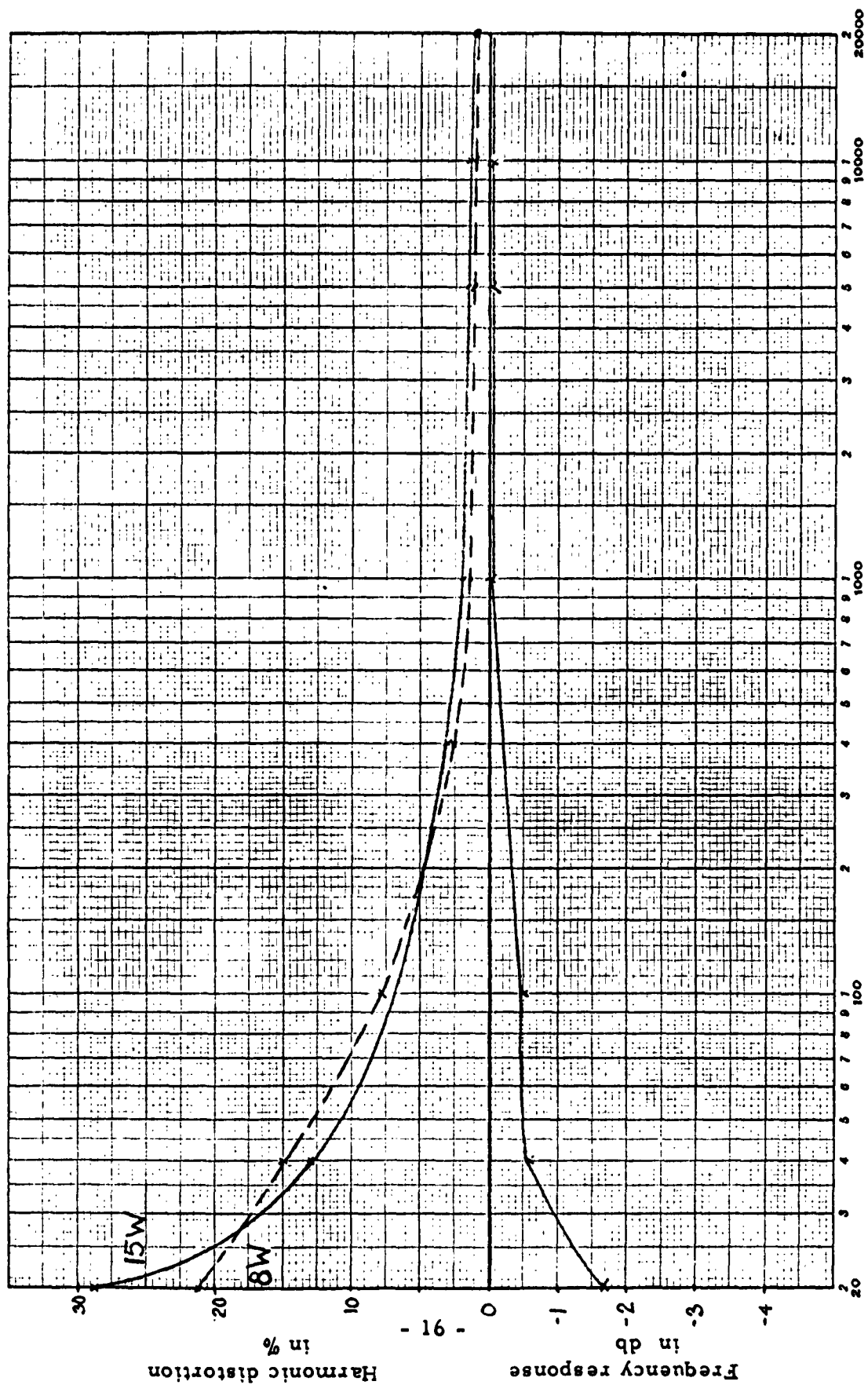
FIGURE 6

Frequency Response and Harmonic Distortion

TABLE 2

Harmonic Distortion

	Output in watts	20 cps in %	40 cps in %	100 cps in %	400 cps in %	1 kc in %	5 kc in %	10 kc in %	15 kc in %	20 kc in %
1.	5	0.9	0.83	0.77	0.76	0.74	0.7	0.55	0.50	0.43
2.	8	21.0	15.0	8.7	2.8	1.58	1.25	1.2	1.15	1.05
3.	10	23.5	14.5	8.8	3.0	1.8	1.52	1.35	1.25	1.20
4.	15	29ʹ	13.5	8.5	3.0	1.95	1.68	1.5	1.4	1.35

Amplifier Design

Taking into account the previously described amplifier design considerations, an audio amplifier had been newly designed.

The contract requires four different impedances with different nominal input sensitivities as follows:

(a) <u>at 150 ohm high-gain floating input</u> with -55 dbm nominal input sensitivity.

Where No of db $= 10 \log \dfrac{P_1}{P_{ref}}$ in watts

dbm $P_{ref} = 1$ mw

Power is given in db should be converted to watts

$$\dfrac{P_1}{P_{ref}} \text{ in watts } = \text{ antilog } \dfrac{P_1 \text{ in db}}{10}$$

then

$$E = \sqrt{PZ}$$

P in watts

Z in ohms

Input sensitivity in volt

$$E = \sqrt{(3.16 \times 10^{-6}) \ (.001) \ (150)} = \sqrt{47.4 \times 10^{18}}$$

$$E = .675 \text{ millivolt}$$

(b) <u>at 20,000 ohm bridging floating input</u> with -35 dbm nominal input sensitivity.

$$E = \sqrt{(3.16 \times 10^{-4}) \quad (.001) \quad (20,000)} \quad = \quad \sqrt{.00632}$$

$E = 79.6$ millivolt

(c)   <u>at 600 ohm balanced input</u> and

(d)   <u>at 600 ohm unbalanced input</u> the nominal input sensitivity

is 0 dbm.

$$E = \sqrt{(.001) \quad (600)} \quad = \quad \sqrt{0.6}$$

$E = 775$ millivolt for both inputs

The result of this calculation is tabulated in Table 3.

The basic elements of the tentative tape recorder are shown

in Figure 7 in block diagram. From this, we can see that the input

sensitivity requirements are affected by the choice of the audio input

transformer. The output of this amplifier should match with the record

head.

<u>Magnetic heads</u> are such transducers that either impress a

magnetic pattern onto a magnetizable medium and/or detect magnetic

modulation in the magnetic carrier. Each of the three basic operations

of recording, reproducing, and erasing makes its own particular de-

mands on the magnetic heads involved. It is possible to construct a sat-

isfactory system in which the same head is used in all three operations,

but it is preferable to use a separate head for each operation. The

record, playback, and erase heads are very similar in physical ap-

pearance and internal structure, each one operates in a very distinct

manner.

- 19 -

TABLE 3

Input Requirements for the Record Amplifier

	Input	Impedance ohms	Nominal Input dbm	Sensitivity milli-volt	Input transformer gain	Amplifier Sensitivity in volt
1.	a	150	-55	.675	20	.0135
2.	b	20000	-35	79.6	1.414	.1122
3.	c	600	0	775	10	7.75
4.	d	600	0	775	10	7.75

Input selector
audio input transformer

Input

a
b
c
d

Record Head
(same as playback head)

Playback Head

Audio
Amplifier

Power
Amplifier

Speaker

Power
Supply

Bias-erase
Oscillator

Erase Head

FIGURE 7

Block Diagram of the Basic Taperecorder Elements

A magnetic head to be used for __recording__ purposes should possess the following characteristics:

(1)   The recording field which it generates should be sharply defined.

(2)   The magnitude of this recording field should be proportional to the current through the energizing coil of the head over a range at least as great as the value required to saturate the medium completely.

(3)   The losses in the head should be small and should be as nearly as possible independent of frequency.

(4)   The self-resonant frequency of head should be as high as, or higher then the bias frequency.

(5)   The head should be designed to make good and uniform contact with the medium.

(6)   The head should be convenient to use in operation.

The following requirements must be met in a magnetic head to be used for __playback__:

(1)   The magnetic head should have the highest possible degree of resolution, that is, the effective gap length should be as small as possible.

(2)   Eddy - current and hysteresis losses should be low, and the remanence of the pole-piece material should also be low.

(3)   It should be well shielded from both magnetic and electrostatic fields.

(4)   It should permit good and uniform contact with the medium.

(5)   The self-resonant frequency of the head should be higher than the highest frequency to be reproduced.

Taking the above requirements into consideration, the Brush Instruments Company's Model BK-1090 record reproducer head was purchased, (see attached specification as TABLE 4). The output of this head, just as any other head tends to be proportional to the rate at which the magnetic flux of the tape changes polarity. The lower the frequency, the slower the rate of change and, hence, the less the output. A minor reason for bass loss at the very low end (below 50 cycles) is the wrap effect; that is, the material of the head may adversely affect magnetic coupling between the tape and the playback head gap when the magnetic flux extends an appreciable distance from the tape. The high-frequency response changes with the speed variations; the low-frequency end varies relatively little with tape speed. These and other losses will be described in detail at the discussion of equalization. Besides the input sensitivity requirement the head losses should also be taken into consideration to be able to calculate the output requirement for the record amplifier.

RECORD-REPRODUCE AND ERASE HEADS

.69

.465

.55

.405

.76

.56 RADIUS

.37

X

.320 +.010

¼-32 THREAD

FREE LENGTH OF LEADS
APPROX. 6½ INCHES

AZIMUTH ALIGNMENT ±1°
ALL DIMENSIONS ±.005″
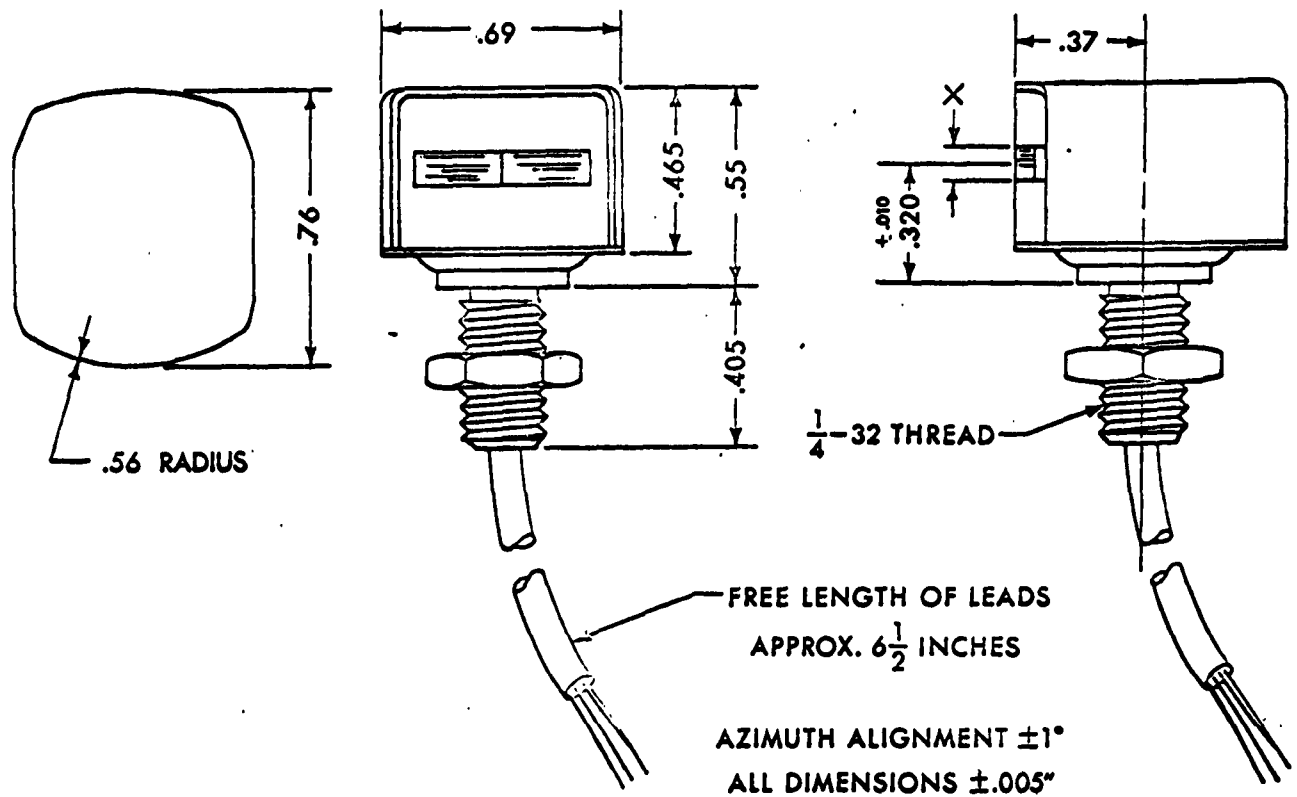
RECORD-REPRODUCE MODEL BK-1090

Track Width...0.090 inch
Gap Length...0.00025 inch
Inductance...550 millihenrys
Resistance..100 ohms

RECORD-REPRODUCE MODEL BK-1091

The BK-1091 is a high impedance version of the
BK-1090, having essentially the same frequency
response and a 6 db higher output. Approximate
inductance, 2.4 henrys.

ERASE MODEL BK-1110

Track Width...0.110 inch
Inductance...55 millihenrys
Resistance..58 ohms
Recommended Erase Current 5-8 ma @ 60 kcps

OUTPUT VS FREQUENCY
BK-1090 RECORD-REPRODUCE HEAD WITH RED OXIDE COATED PLASTIC BASE TAPE

OUTPUT IN DECIBELS 0 db — 1 mv

FREQUENCY IN KILOCYCLES PER SECOND
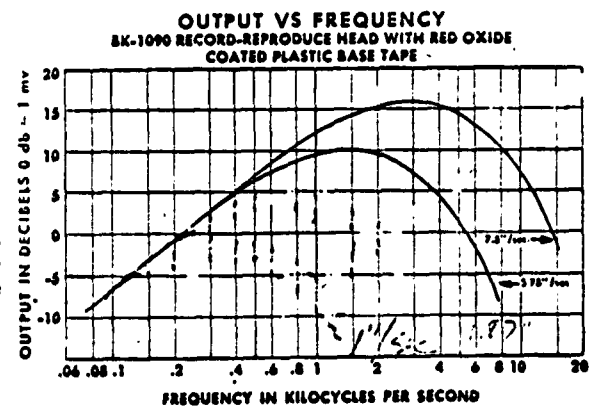
TYPICAL OPERATING DATA:
Bias Current...0.60 ma @ 60 kcps
Recording Current..0.06 ma
Curve Represents Playback Level 8 db Below Saturated Output

TABLE 4

Magnetic Head Specification
- 24 -

Figure 8 shows the output versus frequency of the Brush
Model BK-1090 record-reproducer head at different speeds. Curve
represents playback level 8-db below saturated output with 0.60 ma
(at 60 Kcps) bias and 0.06 ma recording current. The dotted lines
show the ideal response curves at different speeds. This shows that
minimum detectable signal will be below -55 db. The output of the
playback amplifier should match the input of the audio power amplifier.

The first actual design of the amplifier is shown in Figure 9.

TABLE 3 shows the impedance matching requirement for
the record amplifier. The purpose of the impedance matching is to
make an actual impedance look like the impedance required by the
amplifier, as an optimum input (or output) impedance. In input circuits,
matching arrangements change the actual input impedance to a value
that will give the best signal-to-noise ratio compatible with a suitable
frequency response.

A transformer to step up the signal to the grid of the first
tube will improve this situation. It will also contribute some useful
gain so that a smaller amount of gain is required in the amplifier. This
might reduce possible feedback problems. The use of too much step-up
in the input transformer will deteriorate the frequency response.

The audio input transformer is used at a point which is fol-
lowed by the whole gain of the amplifier, hence, it must avoid injecting
any noise or stray signal. Transformers are susceptible to any stray

- 25 -

FREQUENCY IN CYCLES PER SECOND
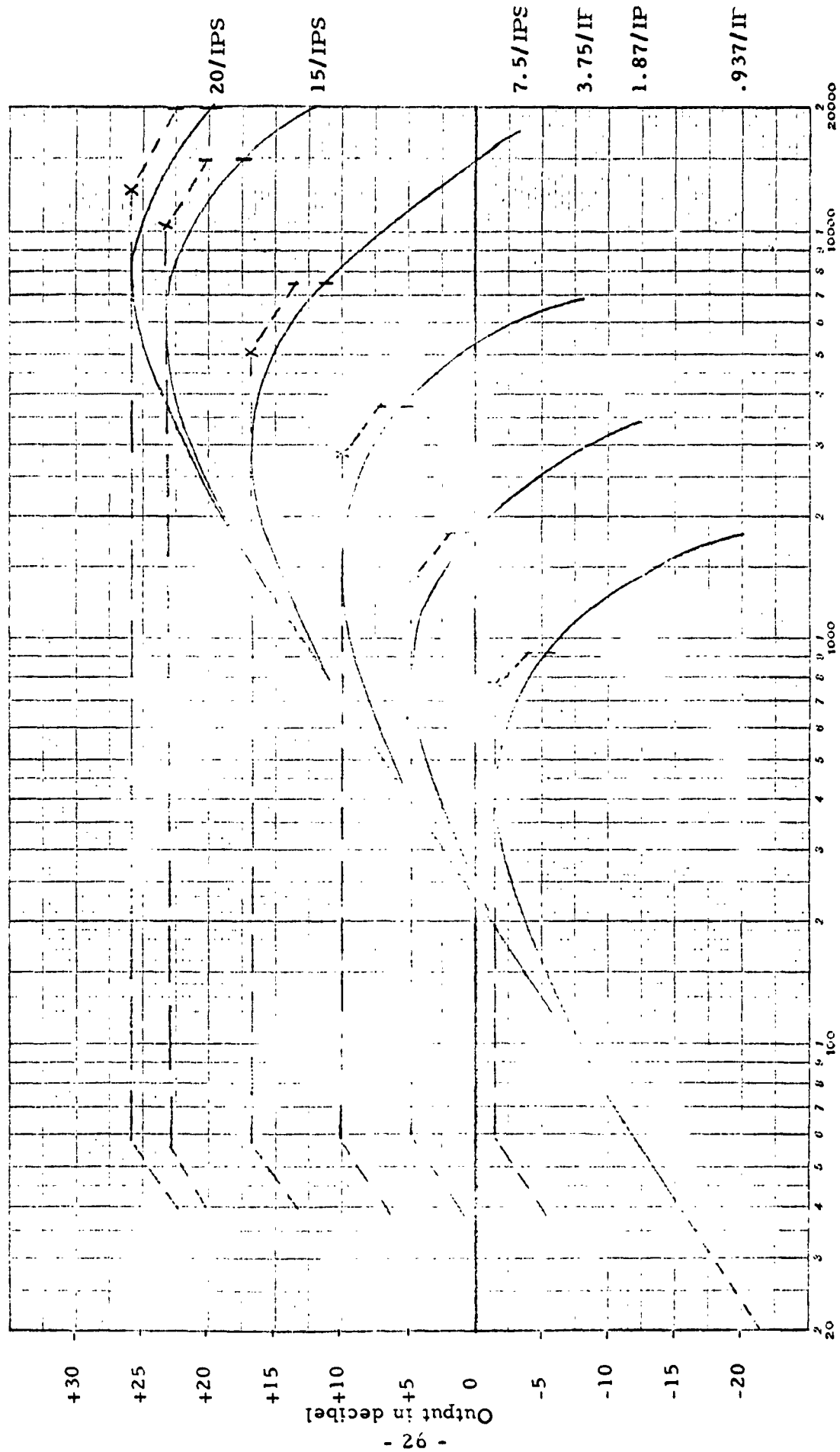
FIGURE 8

Output versus frequency for BK-1090 Head
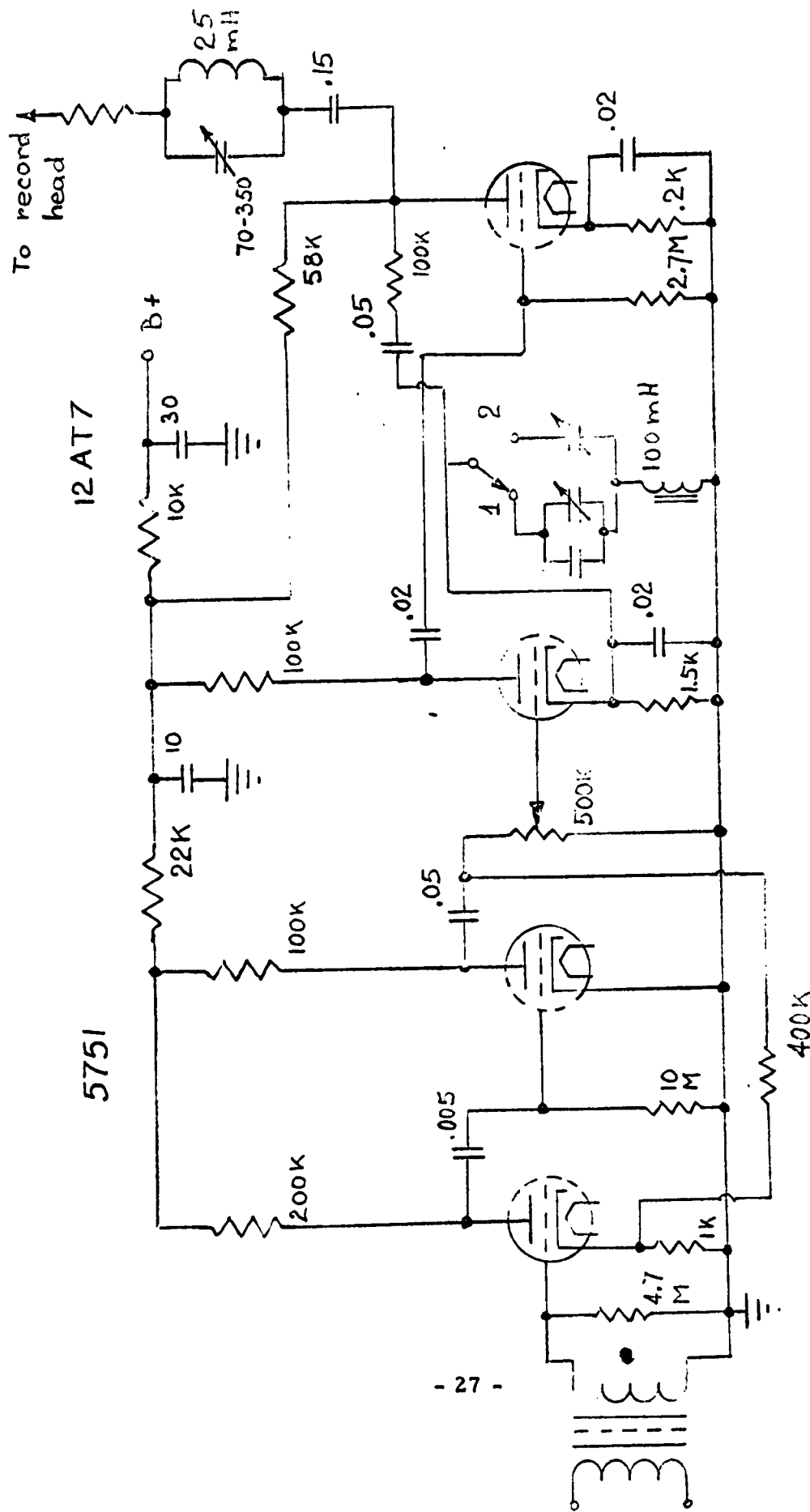
FIGURE 9

Audio Amplifier

- 27 -

interference in their field. The input transformer must, therefore, have as small an external field as possible and must be completely shielded.

Audio Design Company's Model 223C audio input transformer was chosen for the record amplifier. Specifications for this transformer are in TABLE 5.

The equalization network will be inserted between the third and fourth amplifier stages.

The first two stages of the amplifier are conventional R-C coupled audio amplifiers using 5751 twin-triode tubes. Next stage is an R-C coupled amplifier with a recording gain control between the two stages. The equalization network will be inserted between the third and fourth amplifier stages. The last two amplifier stages use a 12AT7 twin-triode tube. The output is matched with the BK-1090 recording head. A parallel L-C network is used to isolate the amplifier from the bias oscillator. The cathode of the last stage has provision for recording current adjustment.

This design was assembled and tested. The over-all-frequency response was inadequate and a strong 60-cycle hum was in the

TABLE 5

Audio Input Transformer
ADC 223C
TF4RX16AF
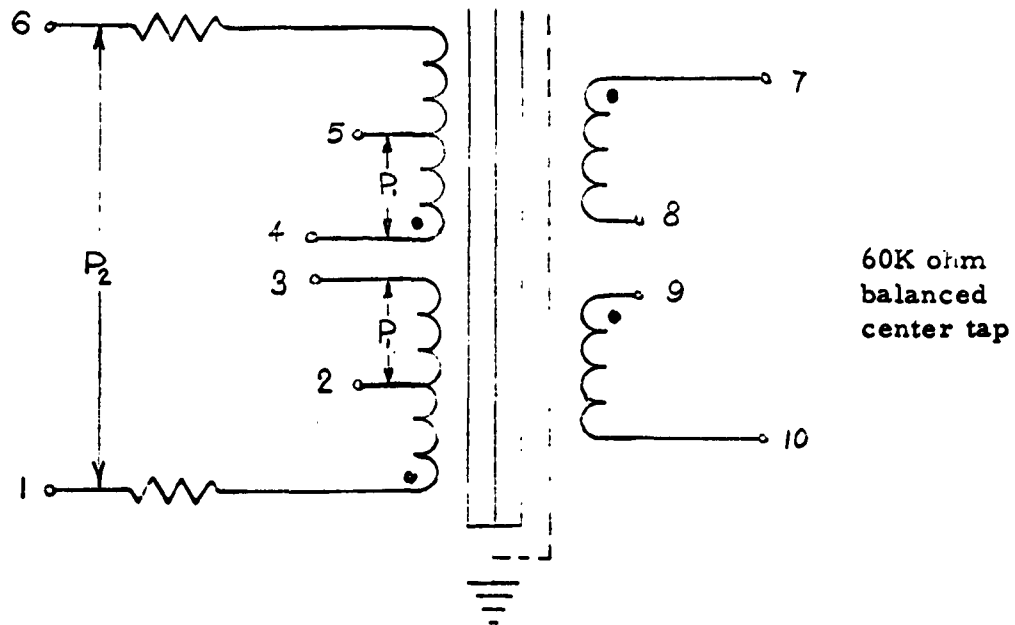
15,000 ohm) +	Pri$_2$
15,000 ohm)	
600 ohm Ser)	Pri$_1$
150 ohm Par)	

This transformer is conservatively rated at $\pm$ 1/2 db from 30 to 15 KC at the maximum rated power 10 DBM. Maximum altitude 50,000 ft.

It has built in primary resistors, balanced to 0.1% or better, making the bridging impedance twice the primary impedance. It is hermetically sealed and meets all requirements of MIL-T-27A.

output. The hum content was localized to the power supply. Up to this time a laboratory power supply (a separate unit) had been used. The hum originated partially in the power supply itself, and partially came from the inadequate bonding between the chassis, power supply and instruments.

Next the design of the power supply was undertaken. The power supply in a tape recorder falls into two distinct groups: one supplies the electronic parts and the other the tape transport.

Power supply for magnetic recording generally follows a conventional design. Since magnetic heads are specifically designed to be particularly susceptible to magnetic fields, strong hum fields from power transformers and reactors must be avoided. Heads should be installed as far away as possible from the transformers and supplementary shields are used around the heads to minimize hum pick-up from power supplies.

Since the audio amplifiers are very susceptible to hum it was decided that a highly filtered power supply and D-C filament voltage supply will be designed. For these power supplies silicon rectifiers will be used and a highly efficient (very low ripple factor) filtering system will be applied.

The Chicago Standard Transformer Corporation's Model MS-90031 power transformer was considered with a double pi capacitor input L-C filter using the same company's Model RH-12200 filter choke.

The filament supply uses silicon rectifiers in bridge configuration with a pi, capacitor input, R-C filter. The power supply design was accomplished but never assembled because the contract was amended for a two-channel system.

This completes the description of design and fabrication of the bread board model up to the end of June 1962.

TWO-CHANNEL OPERATION

On June 14, 1962, Mr. Jack Unger called from Fort Monmouth and requested Reed Research to generate a cost estimate on a dual channel, three-head system with five-watt output amplifier.

Proposal and cost estimate for this dual-channel amendment was mailed on 21st of June 1962.

The proposed contract modification was received at Reed Research on 30 July 1962, but as was stated in Progress Report No. 2 the effort in July already was directed toward the two-channel unit.

The new dual channel three-head arrangement is shown in a simple block diagram in Figure 10. Here for each channel two audio amplifiers are used: a record amplifier and a reproduce (playback) amplifier. This reproduce amplifier will be called "playback amplifier" to distinguish it from the record amplifier.

As a logical step, we redesigned the power supply according to the dual-channel requirement.

For the main power supply the Thordarson 27R85 power transformer was used. For rectification the GE-IN 547 general purpose 750-ma silicon rectifiers were used in a bridge configuration as shown in
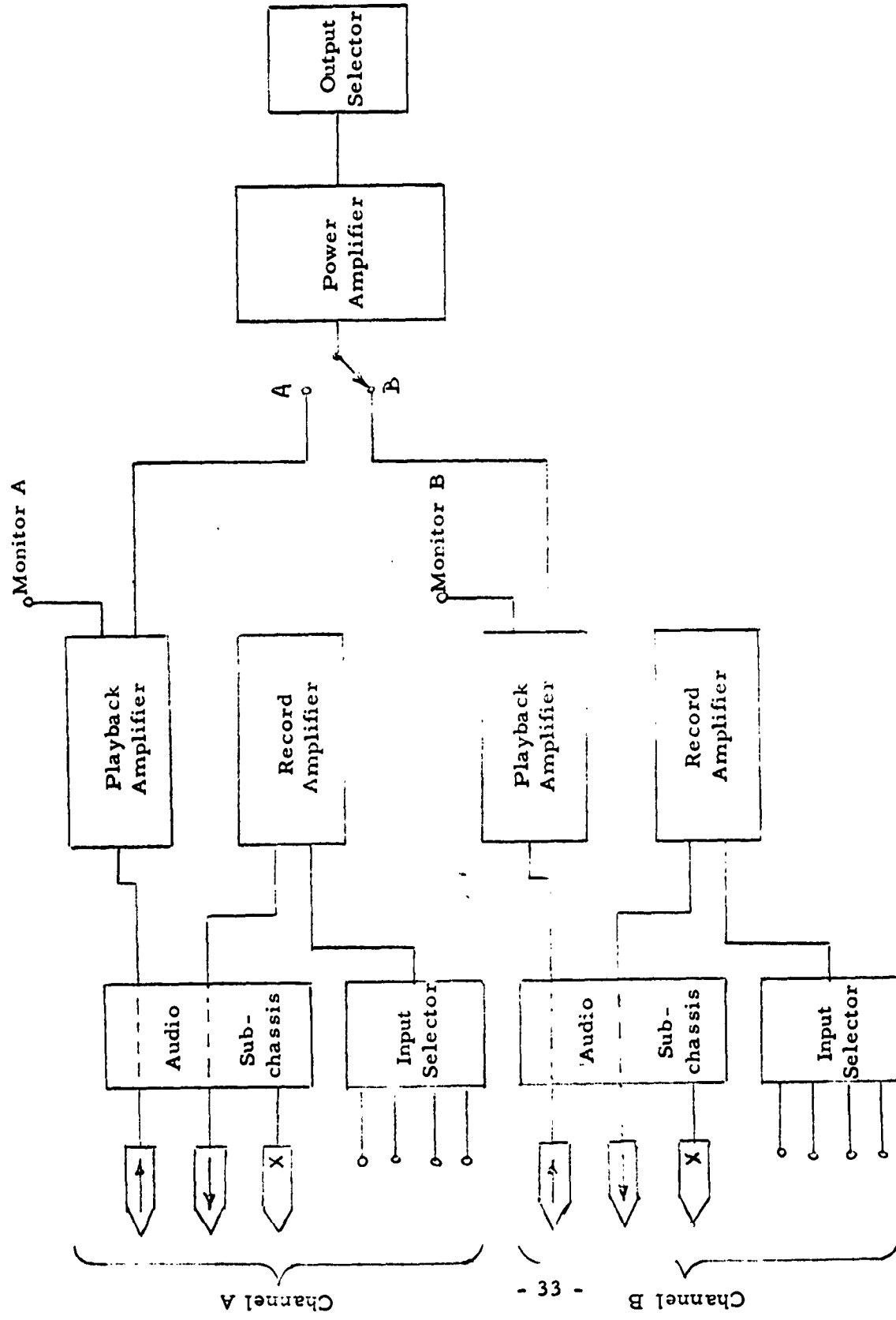
FIGURE 10

Dual Channel Tape Recorder With Three Heads

Figure 11. Filtering is accomplished by a capacitor input, double pi, L-C filter using two Thordarson Model 27C29 reactors. This transformer has a five-volt filament winding which is utilized for the tape transport clutch power supply, therefore a separate filament transformer was necessary.

Thordarson Model 27F58 filament transformer supplies the filament power. For rectification the GE-IN 1614   5 ampere, stud mounted silicon rectifier was applied in a bridge configuration. A capacitor input R-C filter was used in pi configuration. The values of the filter components had been calculated according to the data given in the GE Semiconductor Rectifier Component Guide. (2nd Edition)

The three-head system requires beside erase and recording heads a third head for the playback and monitoring (instantaneous playback while recording), and dual-track heads are necessary.

The Brush Instrument Company's Stereo Model BK-1072 record, reproduce, and erase heads were chosen to comply with the requirements of Amendment No. 1. These are three dual-track heads for each purpose, i.e., record, reproduce, and erase (see specification in TABLE 6). The typical output versus frequency curve is only slightly different from that of the previously used Model BP-1090. This made it possible, with slight modification, to use the same record amplifier.

Thordarson 27R85

IN547 (4)

Thordarson 27F58

IN1612 (4)
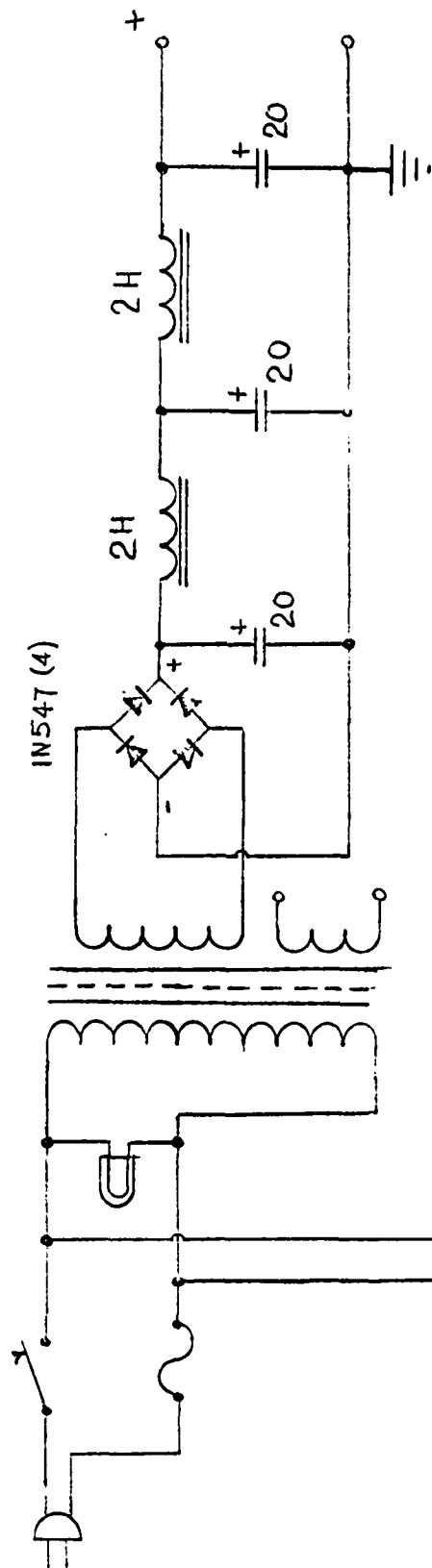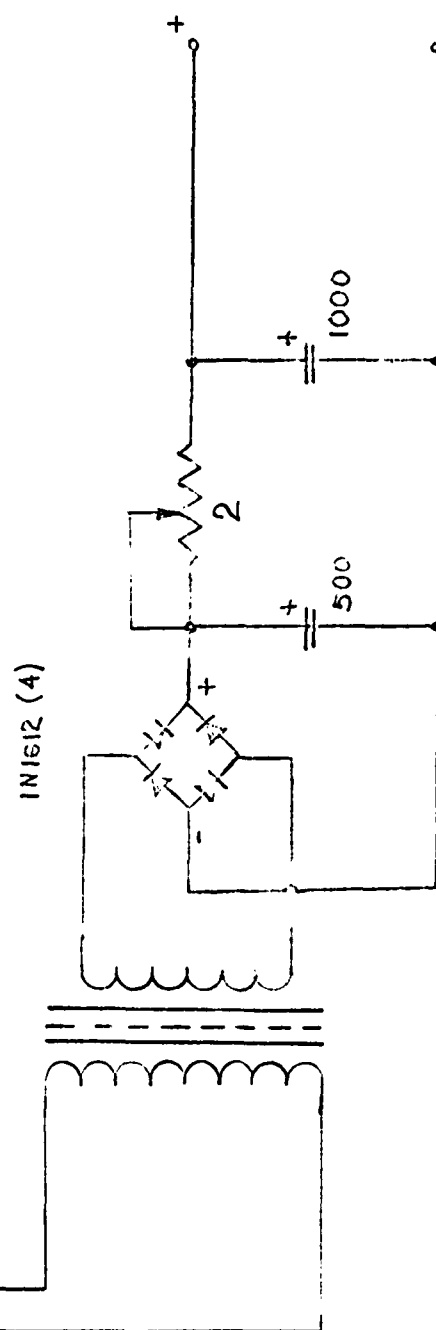
FIGURE 11

Power Supply

- 35 -

RECORD, REPRODUCE AND ERASE HEADS
Stereo Model BK-1072 Series

Model	X	Y
BK 1072	.070	.100
BK 1072R	.090	.080
BK 1072E	.100	.070
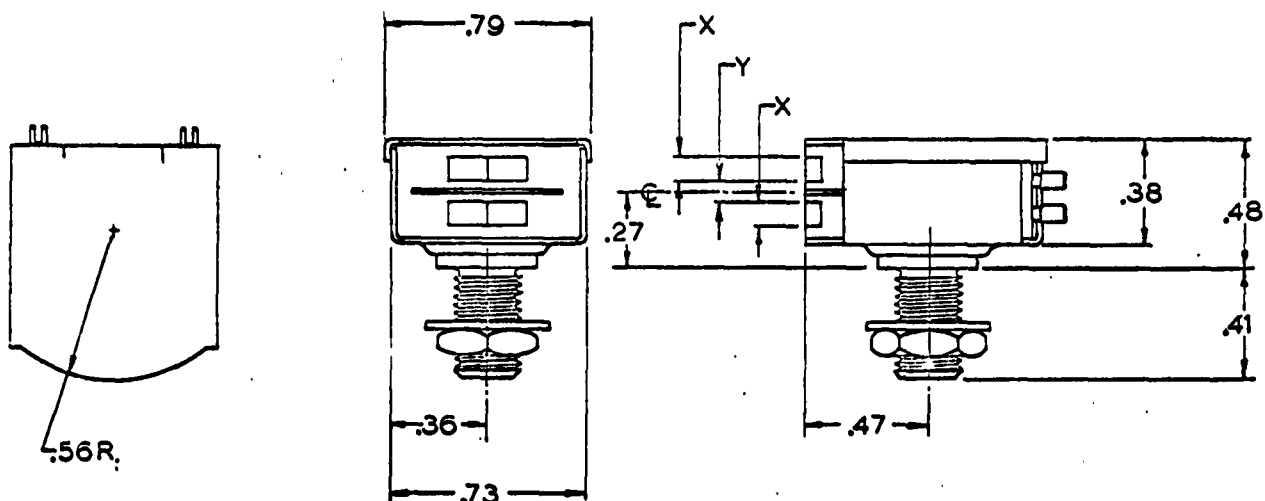
RECORD-REPRODUCE MODEL BK-1072

Gap length. . . . . .00025 inch
Inductance . . . . 590 millihenrys @ 1 kc.
D.C. resistance . . . . 155 ohms.
Bias current . . . . .65 ma. @ 60 kc.
Record current . . . . .065 ma.

RECORD MODEL BK-1072R

Gap length . . . . .0007 inch
Inductance . . . . 11.5 millihenrys @ 1 kc.
D.C. resistance . . . . 17 ohms.
Bias current . . . . 4 ma. @ 60 kc.
Record current . . . . 0.35 ma.

ERASE MODEL BK-1072E

Gap length . . . . .007 inch
Inductance. . . . . 48 millihenrys @ 1 kc.
D.C. resistance . . . . 34 ohms.
Erase current. . . . . 20 ma. @ 60 kc.

TYPICAL OUTPUT VS FREQUENCY
RECORD AND PLAYBACK WITH BK-1072 ON 3M 111 AP MAGNETIC
TAPE OR RECORD WITH BK-1072R PLAYBACK ON BK-1072.
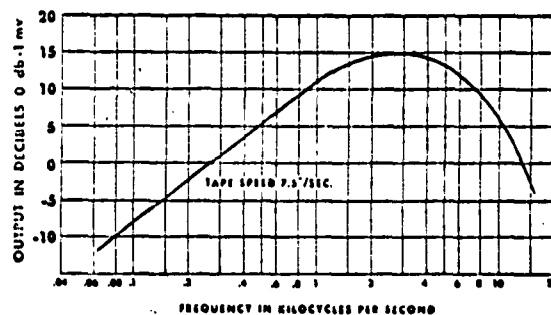
Curve represents playback level 8 db below saturation.

TABLE 6

Dual Track Magnetic Head Specification

The input sensitivity of the playback amplifier must be matched with the output of the reproduce head, hence a high-impedance head was chosen to avoid the necessity of another audio input transformer just for impedance matching.

Figure 12 shows the output versus frequency of Brush Model BK-1072 record-reproduce head. This curve represents playback level 8-db below saturated output with 0.60-ma (at 60-Kpcs) bias current. The ideal response curve is at 13.2-m volt level and this shows that the minimum detectable signal will be below -50-db. This will determine the input sensitivity of the playback amplifier.

The playback amplifier is a three-stage R-C coupled audio frequency amplifier utilizing a 5751 twin-triode and a half 12AT 7 WA twin-triode tube as shown in Figure 13. There is a feedback loop between the cathode of the first stage and the plate of the second stage. The volume control is after the second stage. The output stage has a direct (transformer less) output to a shorting head phone jack. A three position selection switch provides single or dual-channel playback or monitoring.

The new dual channel setup has only one power amplifier. This is basically the same, the only difference is that for output tubes the miniature 6AQ5 beam power tubes are used. This tube is adequate
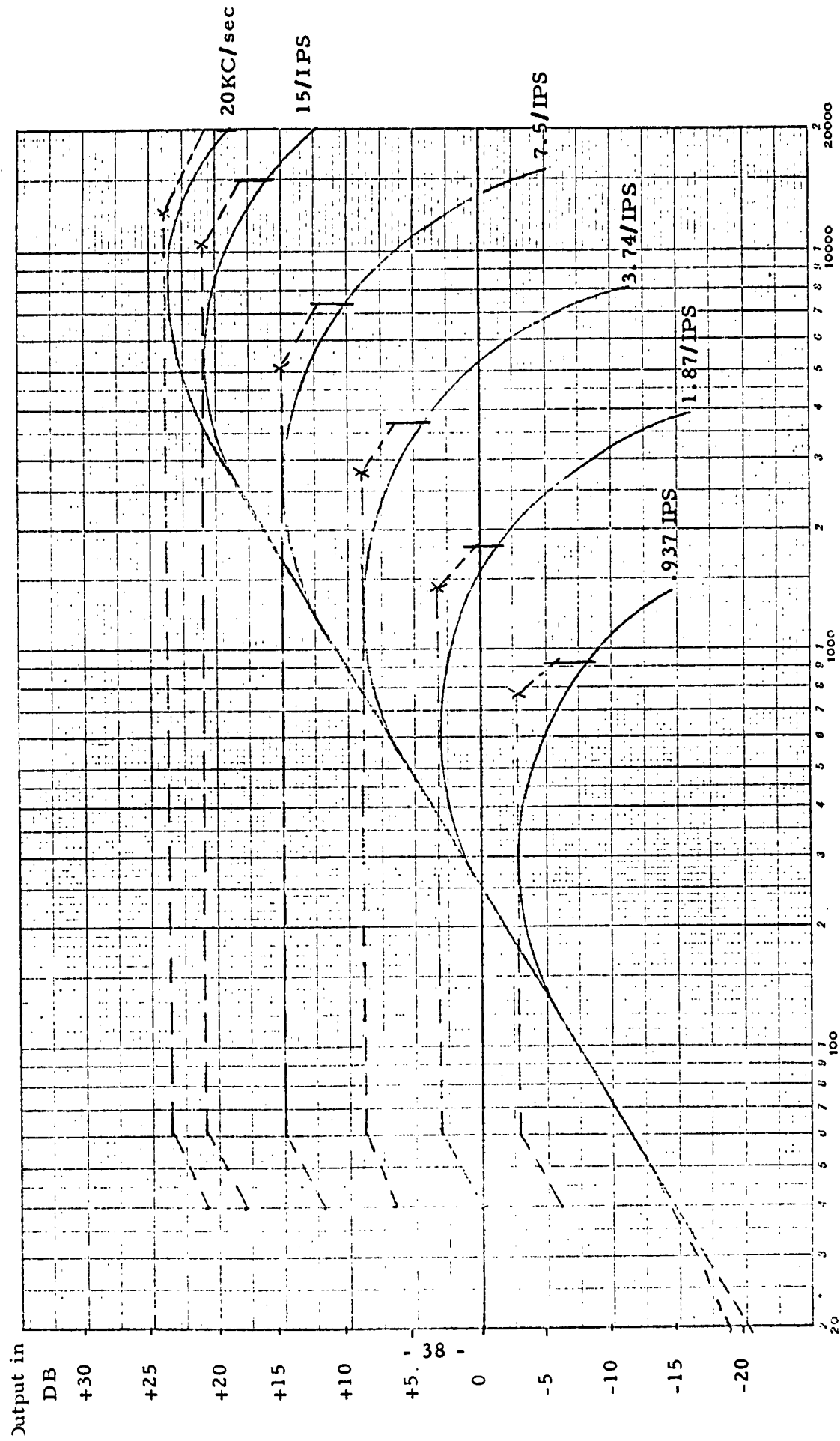
FIGURE 12

Output Versus Frequency for Brush BK-1072 Magnetic Head
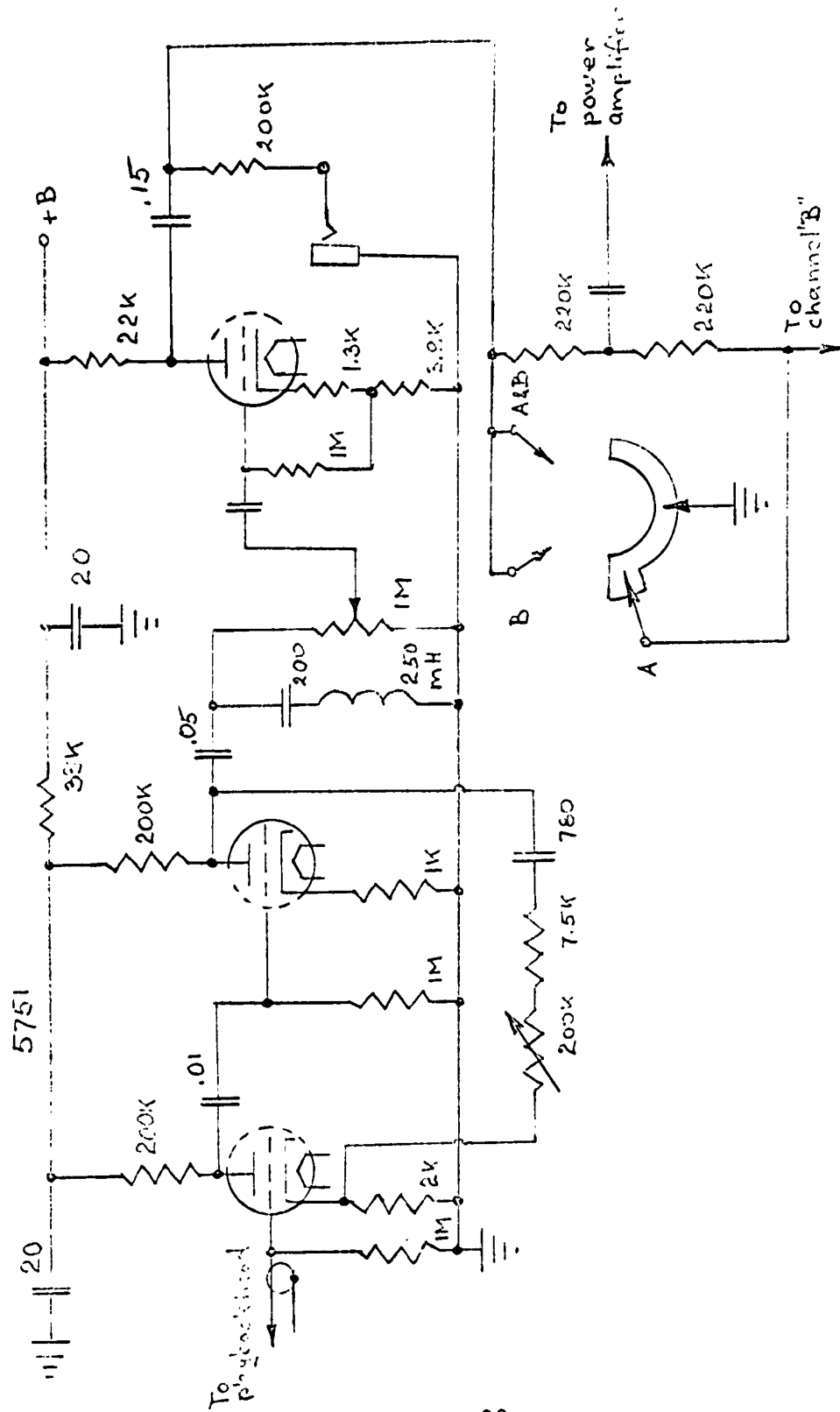
FIGURE 13

Playback (monitor) Amplifier

to supply five-watt output power and at the same time is smaller, lighter and dissipates less heat.

Since the electronic part and the tape transport are on a separate unit a long connecting cable is necessary from the heads to the amplifier inputs. Since the output of the heads are high impedance (by choice) a long cable will cause attenuation of high frequencies. This will not occur if we make the output a low-impedance output circuit using a cathode follower stage right near the head assembly.

This cathode follower circuit was built on the so called "audio subchassis." The circuit used a 5814 twin triode (separate cathode follower stage for each channel) as shown in Figure 14.

On this same chassis will be located the oscillator circuit for bias and erase current and the rectifier circuit for indication of bias and erase currents.

The assembling (breadboarding) of the so far mentioned design was completed during the first week of August 1962 and different measurements were made separately on the recording amplifier and playback amplifier concerning:

        (1)   frequency response

        (2)   harmonic distortion

        (3)   gain

        (4)   hum and noise

½ 5814

Cannon
DPD 12-C4-34P

.1

1K

22K

1.5M

Playback head
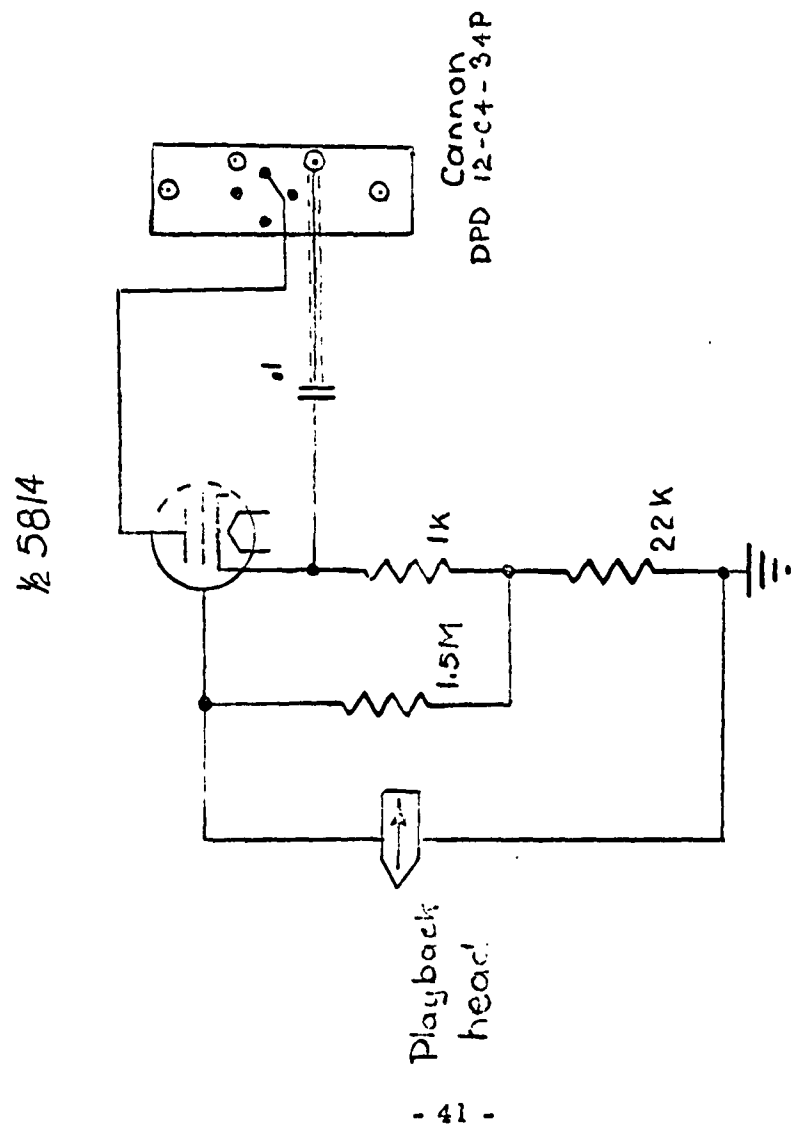
FIGURE 14

Cathode Follower Circuit

Frequency response of the playback amplifier was tested first with different amounts of feedback as shown in Figure 14a. Experiment with different playback boost is shown in Figure 15. Frequency response curves are shown on Figure 16 with different values in the output of the playback amplifier. These were the first rough relative measurements to determine the necessary further equalization. The test setup used for frequency response measurements is shown in Figure 17. For output detector a VTVM and an oscilloscope was used.

After these measurements the first approach for frequency equalization was the circuit shown in Figure 18a. This circuit was inserted in the feedback loop between the first stage cathode and the second stage anode. This equalization circuit gave an almost perfect response curve at high speed as shown in Figure 19a. It was erratic at low speed as shown in Figure 19b. No tape transport was yet constructed, hence the "high" and "low" speeds were simulated by varying the input signal as functions of tape speed and frequency in accordance with Figure 12.

Following this other equalization circuit configurations were tested without achieving the required result. Finally the circuit shown in Figure 18b was inserted into the feedback loop and several minor changes were made in other parts of the playback amplifier which resulted in the desired response curve as shown in Figure 20a and b.

Harmonic distortion was spot checked after each new and final

- 42 -

FREQUENCY IN CYCLES PER SECOND
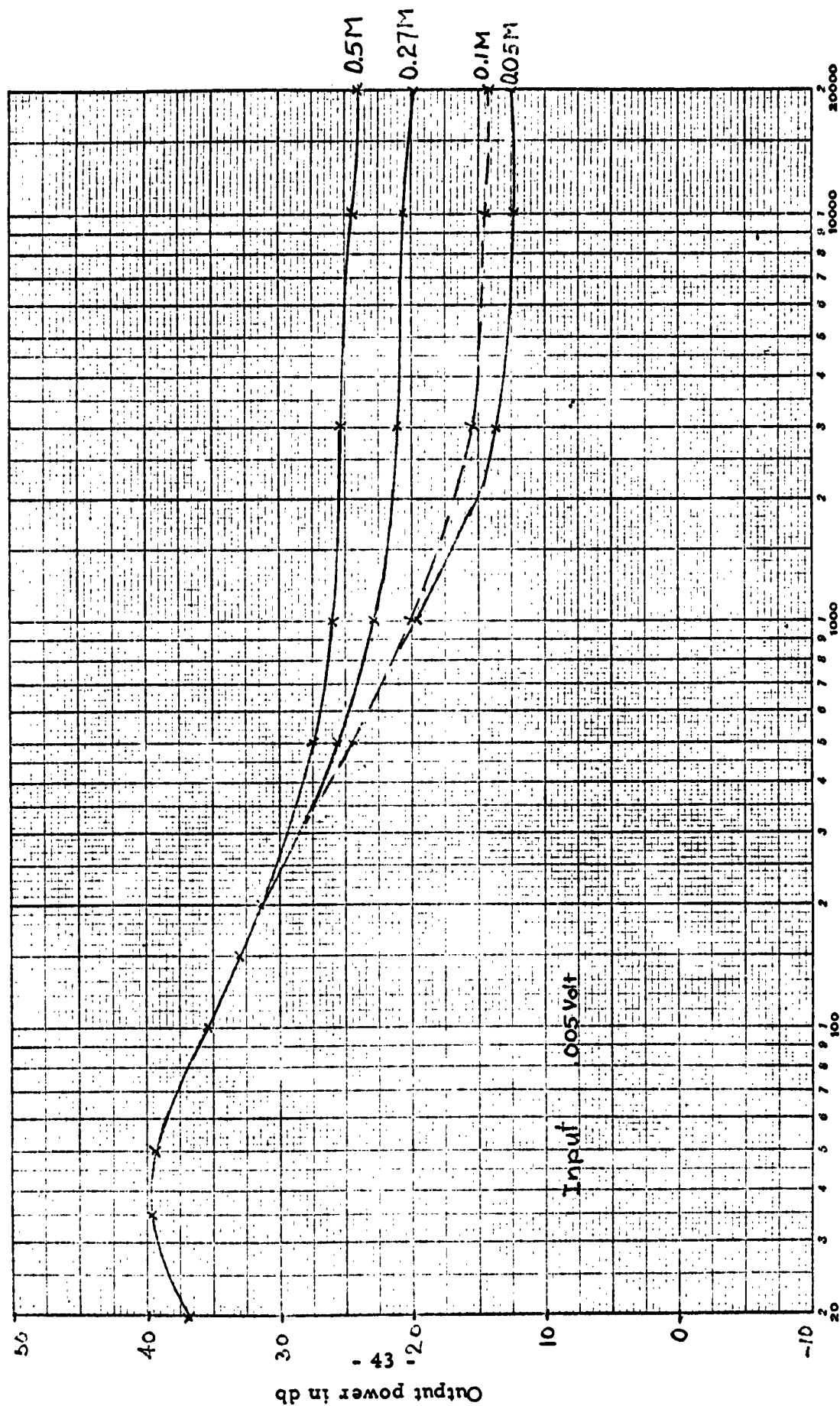
FIGURE 14a

Playback Amplifier Frequency Response with Different Amount of Feedback

Output power in db

Input   0.05 Volt

0.5M
0.27M
0.1M
0.05M

FREQUENCY IN CYCLES PER SECOND
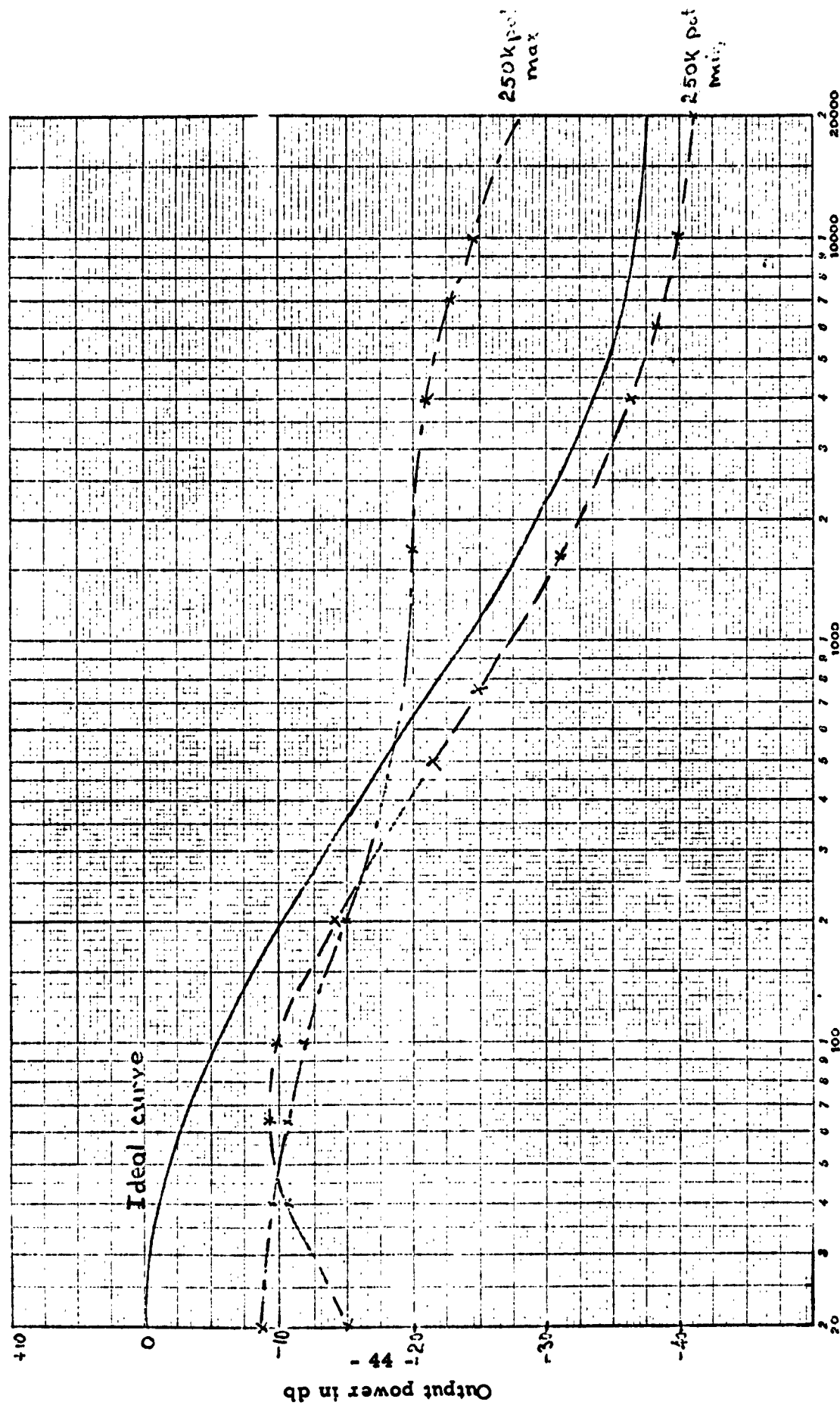
FIGURE 15

Experiment with Different Playback Boost
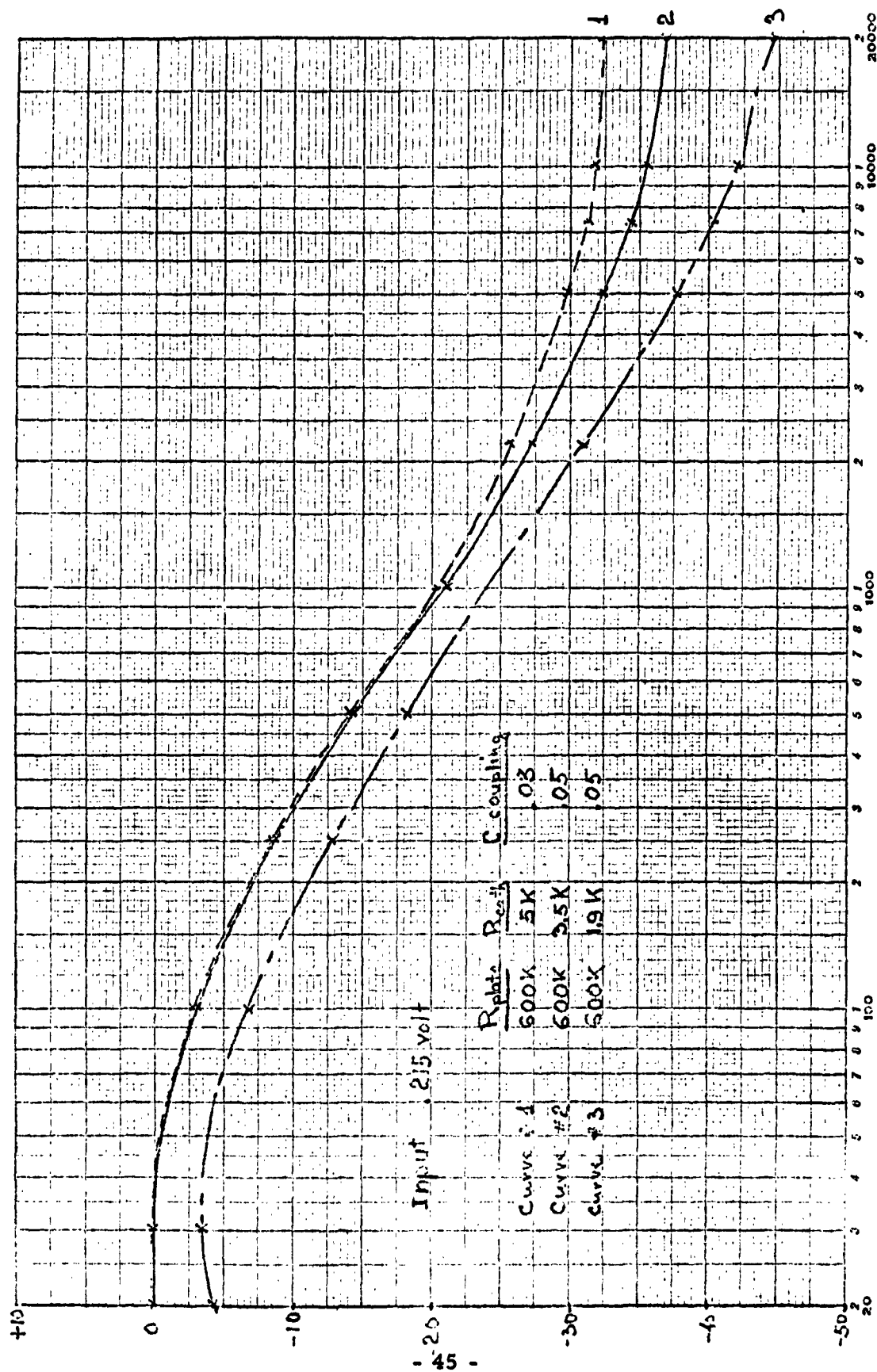
FREQUENCY IN CYCLES PER SECOND

FIGURE 16

Frequency Response of Playback Amplifier with Different Output Parameters

- 45 -
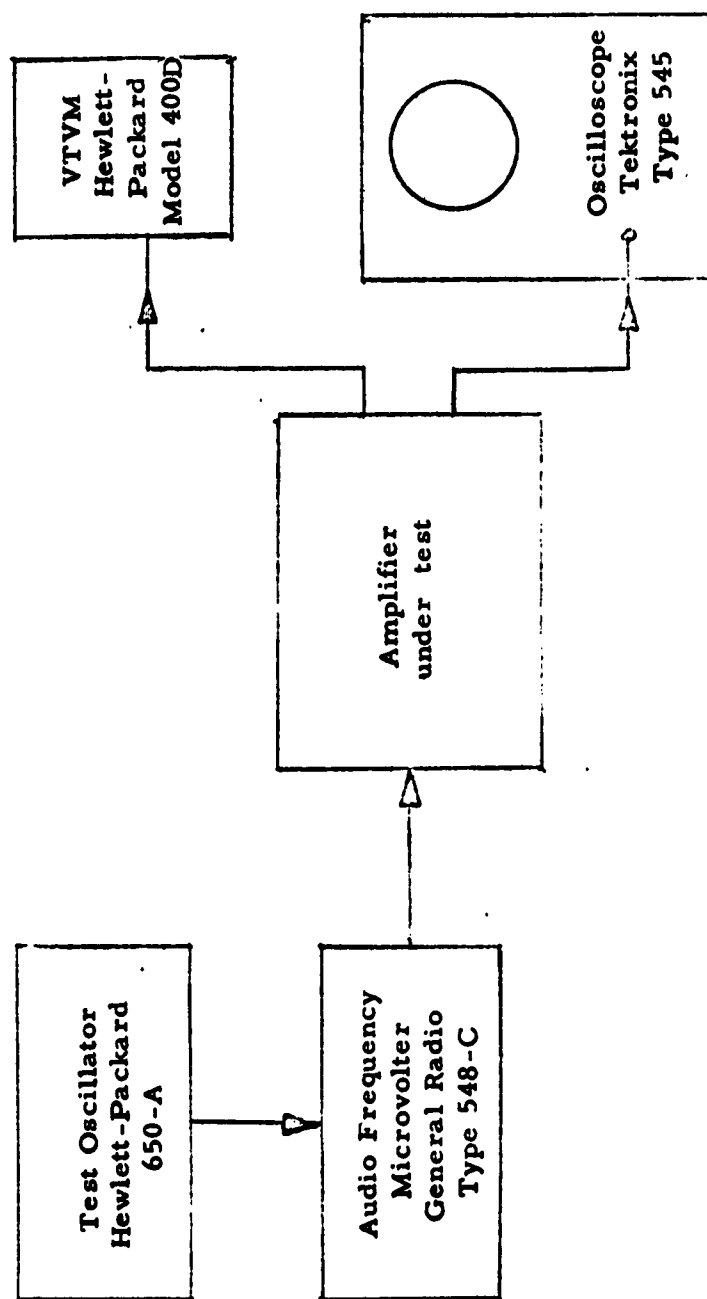
FIGURE 17

Test Set-up for Frequency Response Measurements

.0062 pf

600K

R_a

FIGURE 18a

R_b

4900 pf
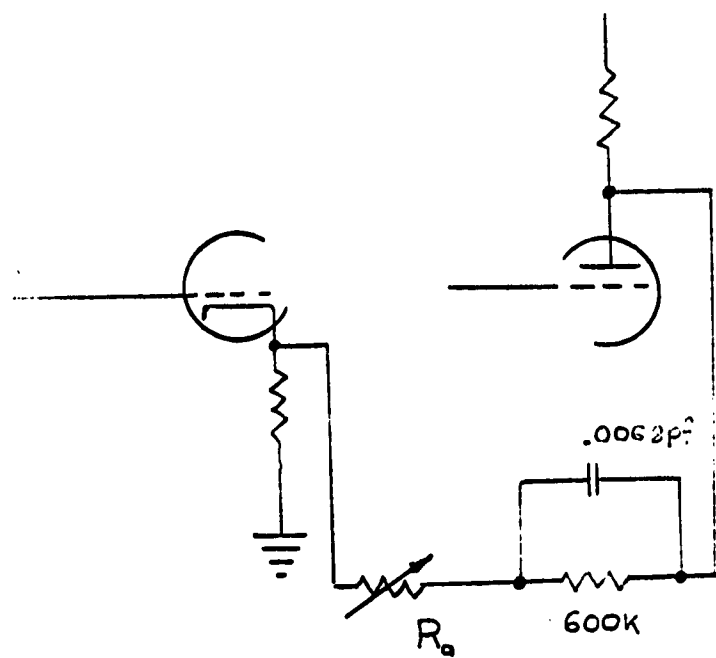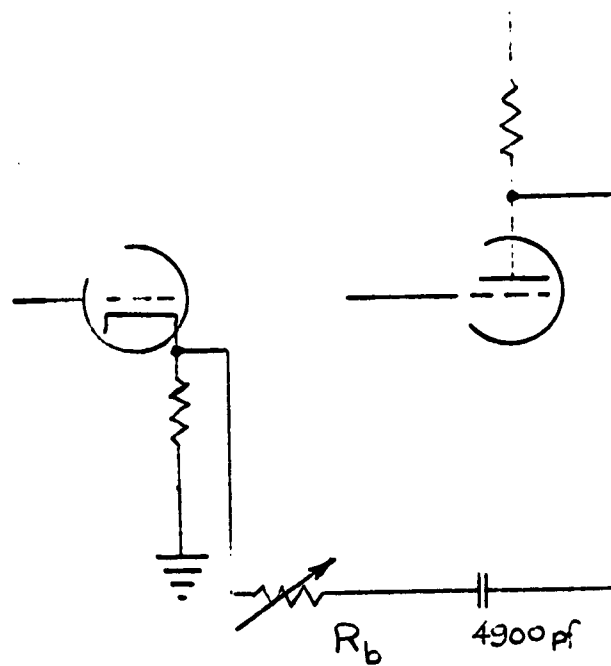
FIGURE 18b

Equalization Circuit for Playback Amplifier

- 47 -

FREQUENCY IN CYCLES PER SECOND
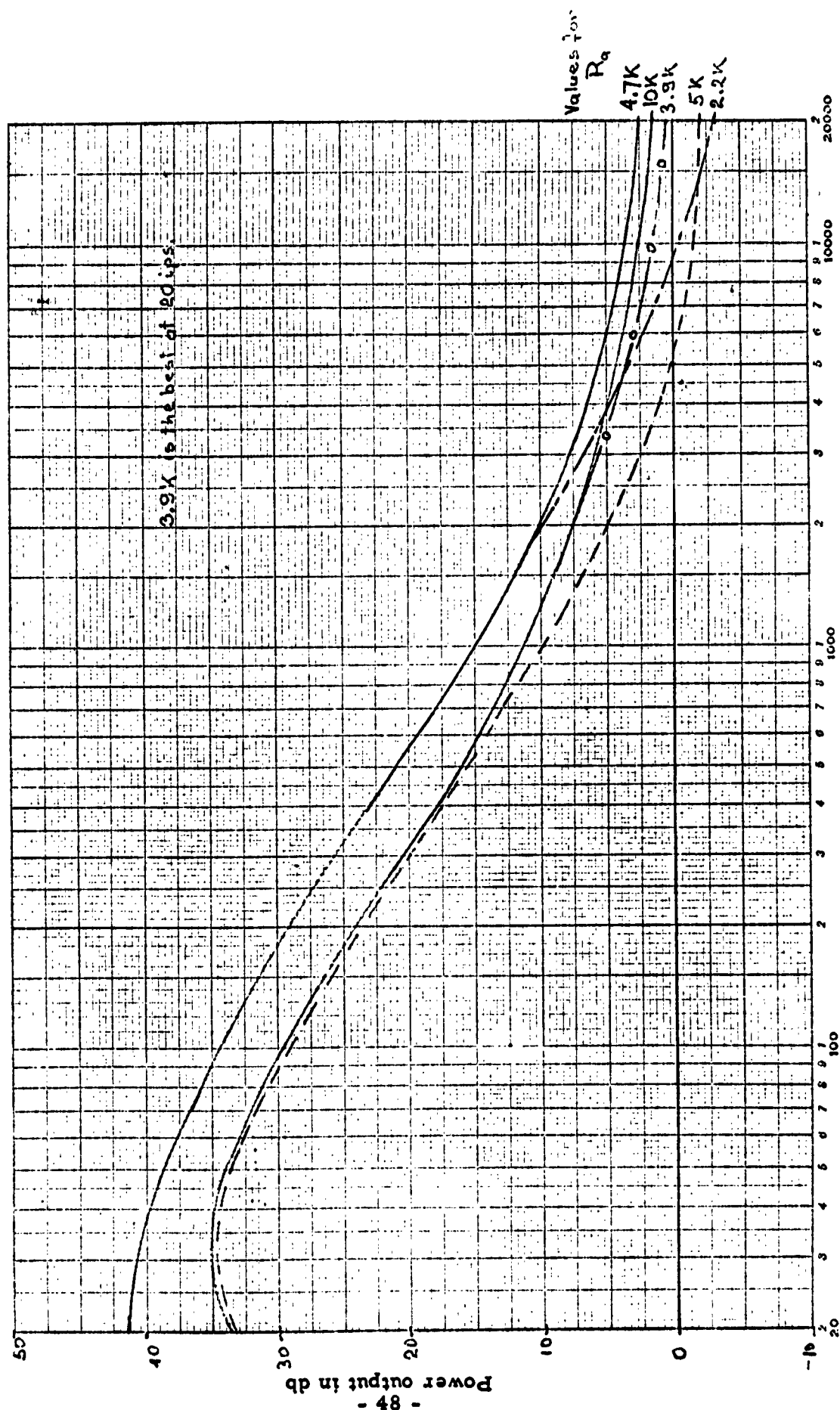
FIGURE 19a

Ideal Bass Boost for Extreme Speeds (20 IPS)

FREQUENCY IN CYCLES PER SECOND
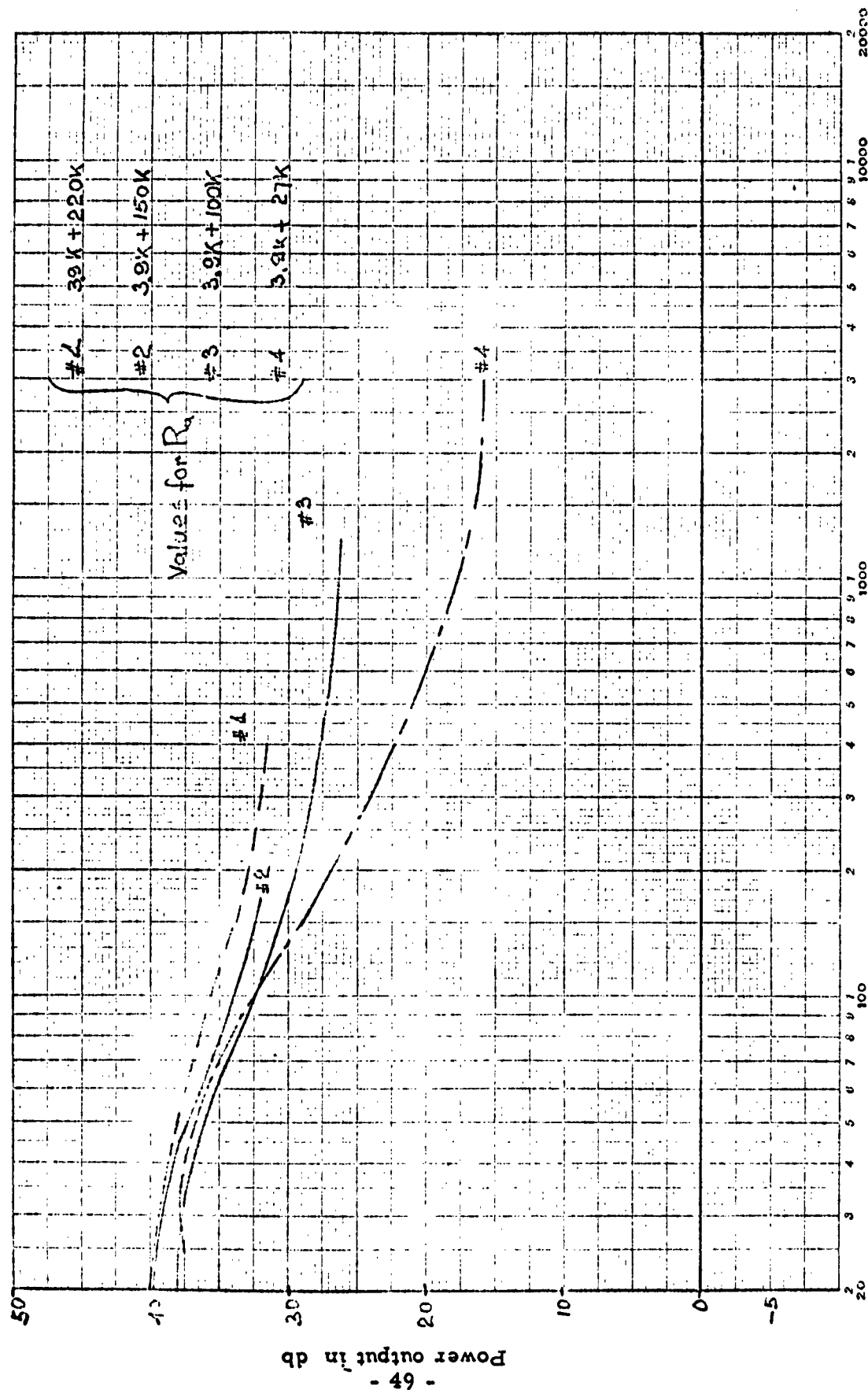
FIGURE 19b

Bass Boost for Extreme Speeds (1 IPS)

- 49 -

FREQUENCY IN CYCLES PER SECOND
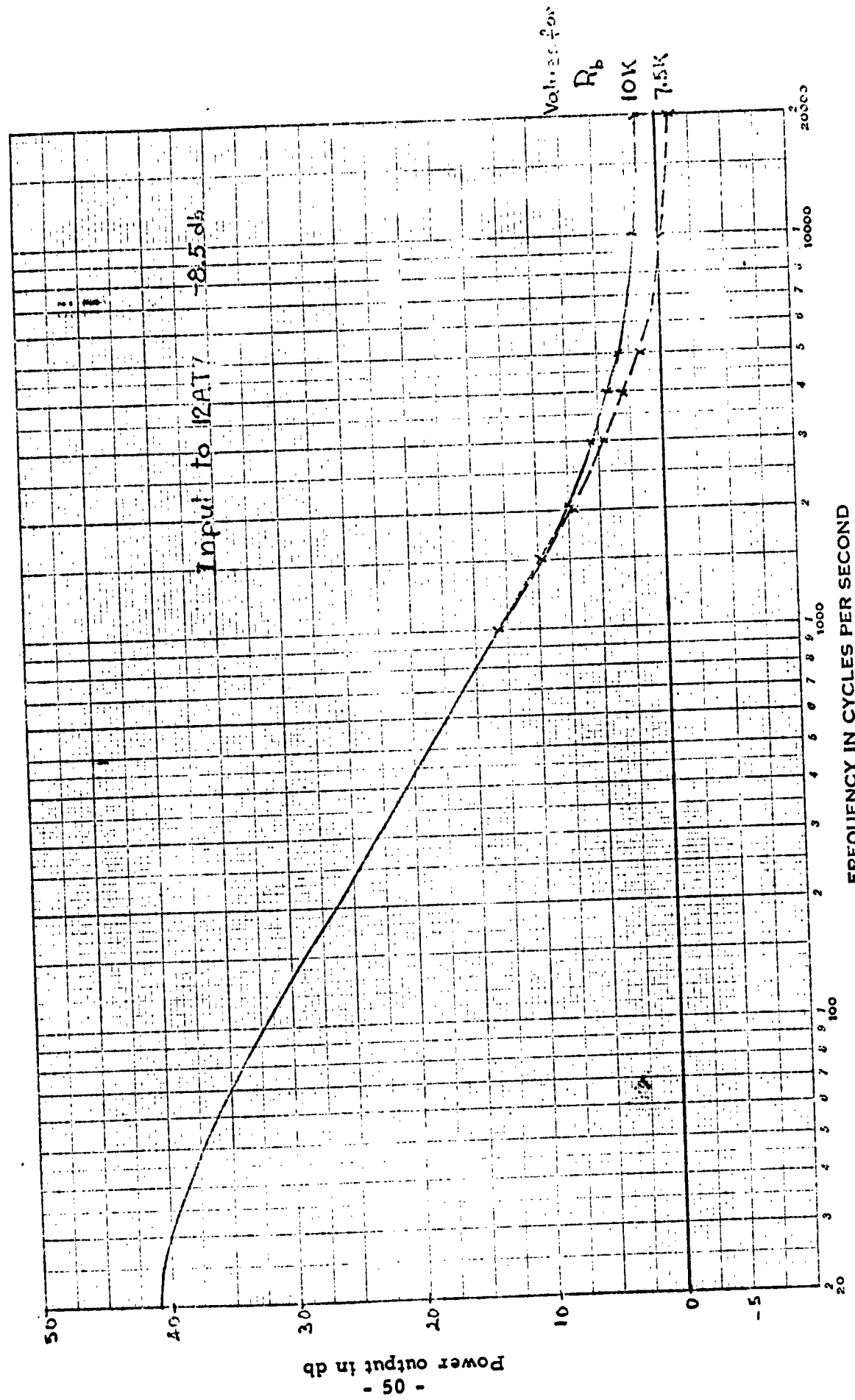
FIGURE 20a

Ideal Bass Boost for Extreme Speeds (20 IPS)
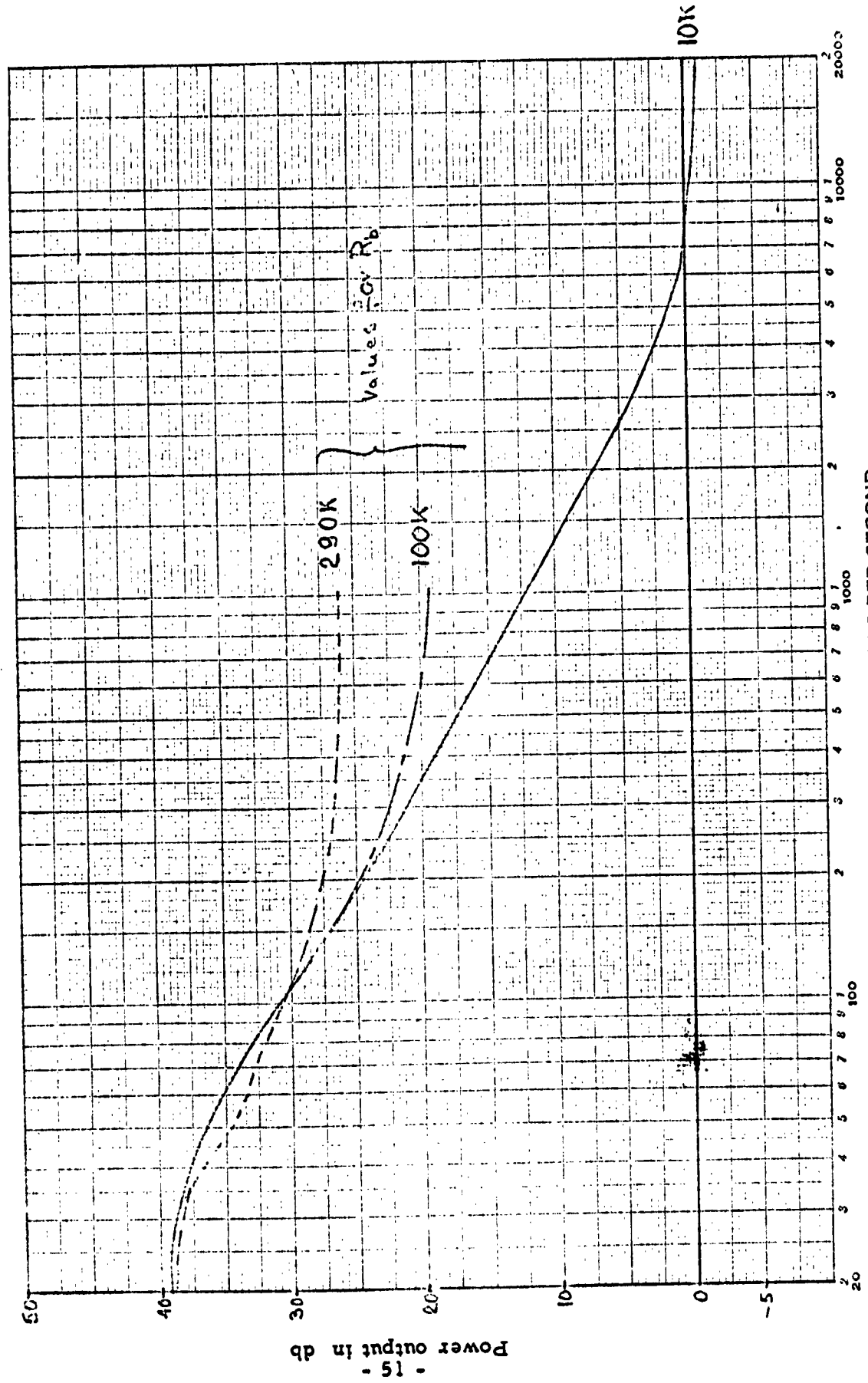
FREQUENCY IN CYCLES PER SECOND
FIGURE 20b
Ideal Bass Boost for Extreme Speeds (1 IPS)

equalization circuits and was always below the required 5% level.

Hum and noise level of the playback amplifier is below -50 db measured across 4-ohm resistive loads.

Circuit diagram of the playback amplifier after modification is shown in Figure 21.

Record amplifier basically remained the same as it was shown in Figure 9. Using the ADC Model 223C audio input transformer the basic connections for each input separately is shown in Figure 22 (cf TABLE 5). The switching of the different input was achieved by using the Centrelab PA-6000 series four-position waffle switch. During the actual wiring of this switch we encountered considerable difficulty in eliminating hum. This was done by careful wiring and lead dressing and finally the whole switching arrangement was shielded from the other components underneath the chassis. Actual final wiring is shown on Figure 23.

The high-gain inputs have a pei nanent connection to the first stage of the record amplifier. This input point is the most sensitive part of the record amplifier. For a connection between the rotary switch and the first grid an extremely short lead must be used.

For low-gain inputs the input connection is made through a switching arrangement to the third-stage grid of the record amplifier. Care must be taken to prevent tube feedback to the first input grid.
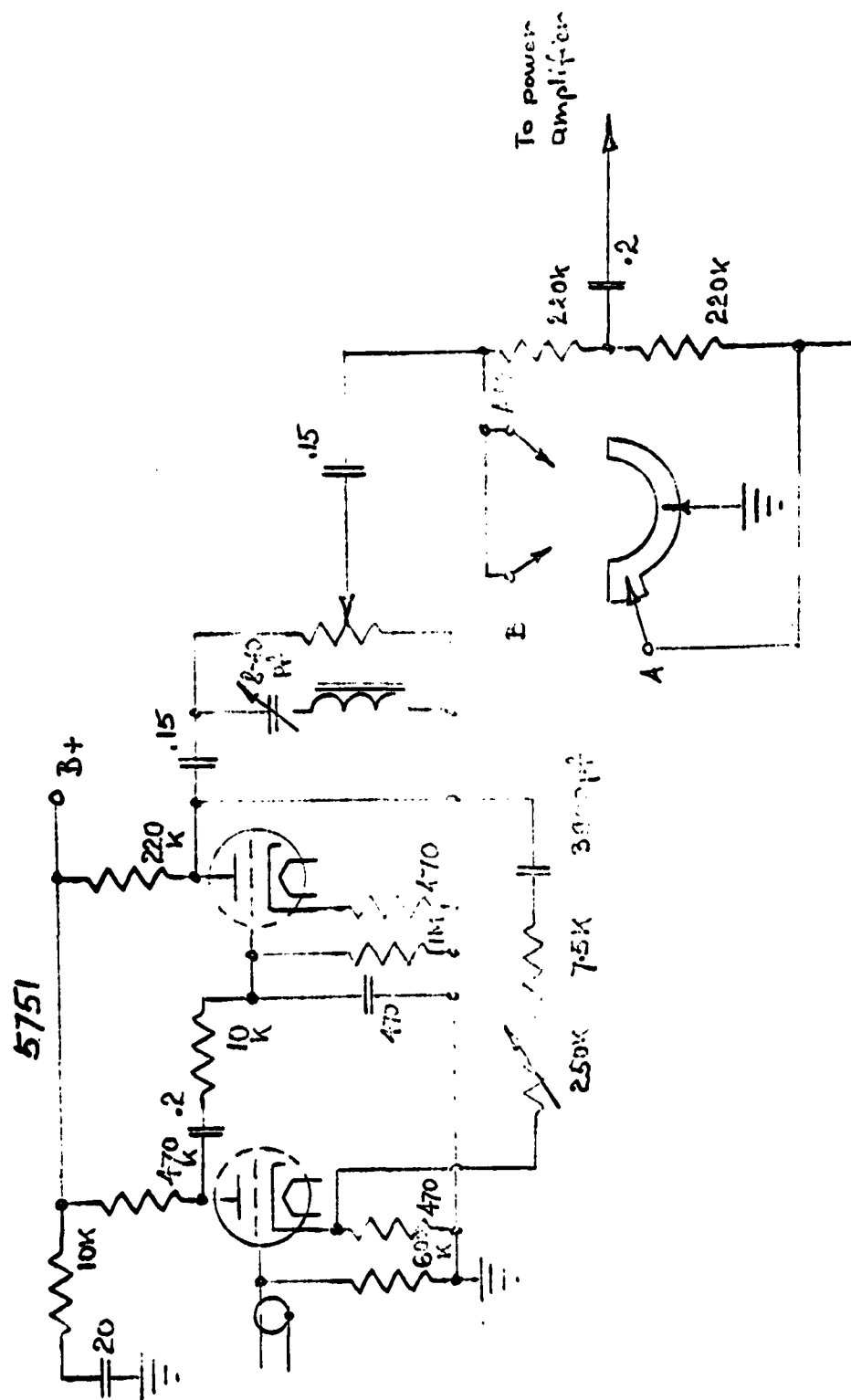
FIGURE 21

Circuit Diagram (modified) of Playback Amplifier
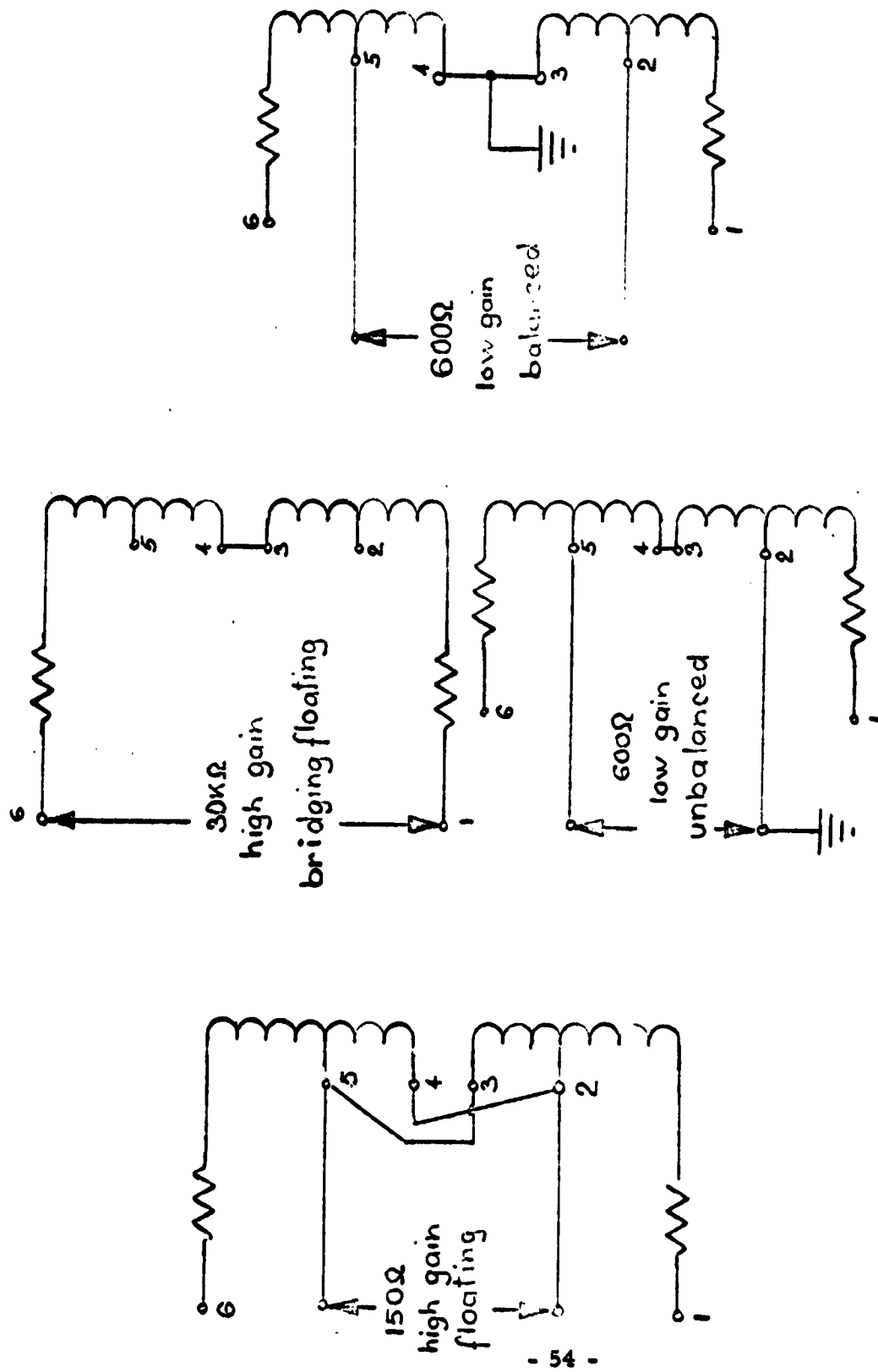
FIGURE 22

Basic Input Connections

- 54 -
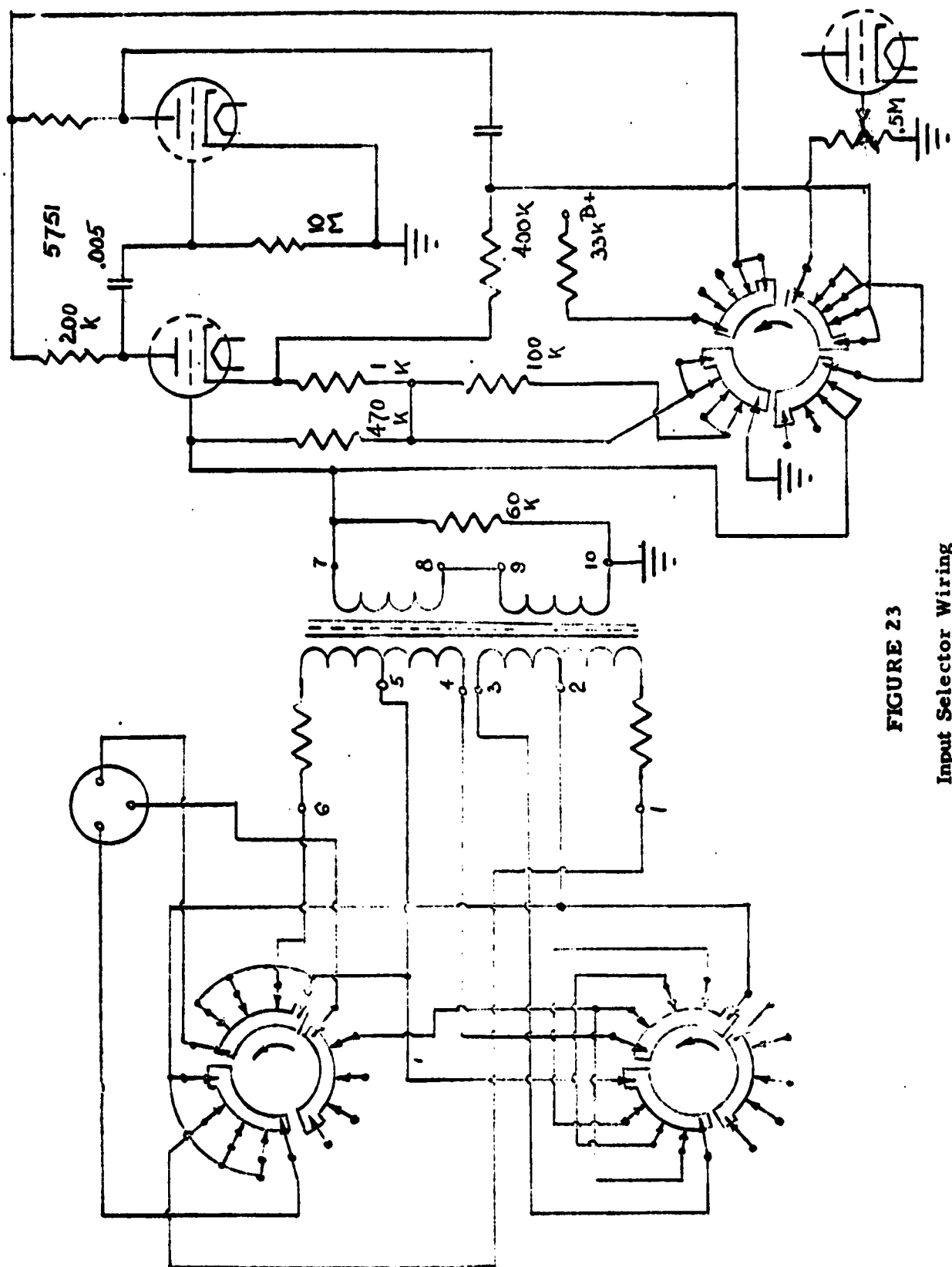
FIGURE 23

Input Selector Wiring

To avoid any interaction between the high and low-gain input the B+ is killed in the first two stages. In this case the first tube grid and cathode are working in a diode configuration as shown in simplified diagram in Figure 24. The cathode resistor is increased in the low-gain mode to reduce grid (as anode) cathode current to a tolerable level. This is accomplished with a separate ground switching arrangement.

Considerable difficulty has been encountered in the record equalization. The energy from the head to the tape at constant current is not a function of the tape speed and will be recorded at the same level (as the actual output of the head) shown in Figure 12. Only high-frequency losses are encountered and may be compensated. A few db record bass boost can be used at the extreme low end of the frequency spectrum to reduce the gain required in the playback amplifier, but the rest of the bass equalization is taken care of in the playback amplifier. The theoretical high-frequency equalization curve is shown in Figure 25.

The first equalization circuit (cf Figure 9) gave the equalization curve as shown in Figure 26. This response curve had satisfactory equalization only in a limited range of tape speeds, therefore, it was changed.

An R-C feedback loop was inserted between the third-stage cathode and the fourth-stage plate as an equalization network. Different component values were used and frequency response of these

FIGURE 24

Simplified Input Diagram for Low Gain Input

FREQUENCY IN CYCLES PER SECOND
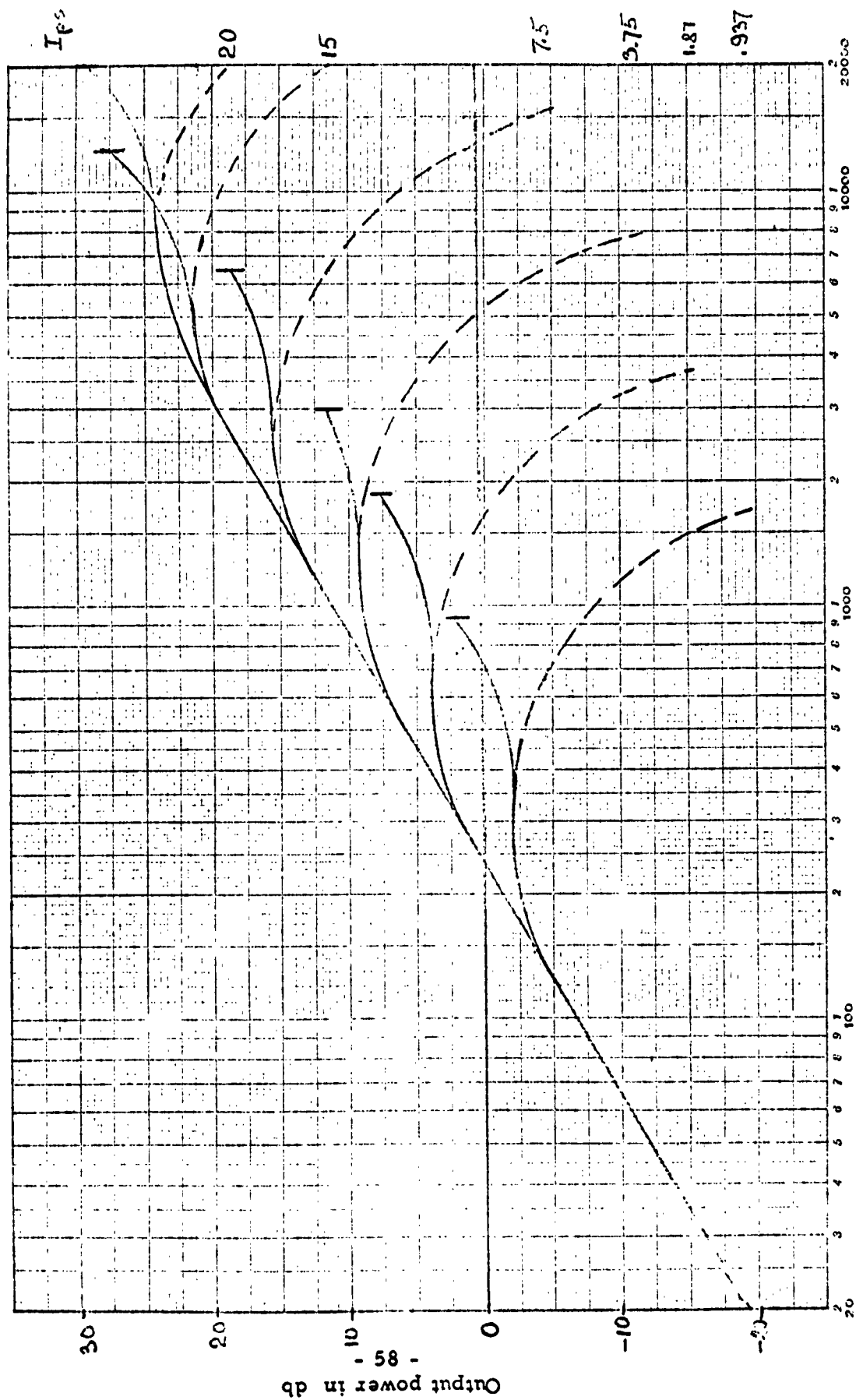
FIGURE 25

Idealized High-frequency Equalization in Record Amplifier
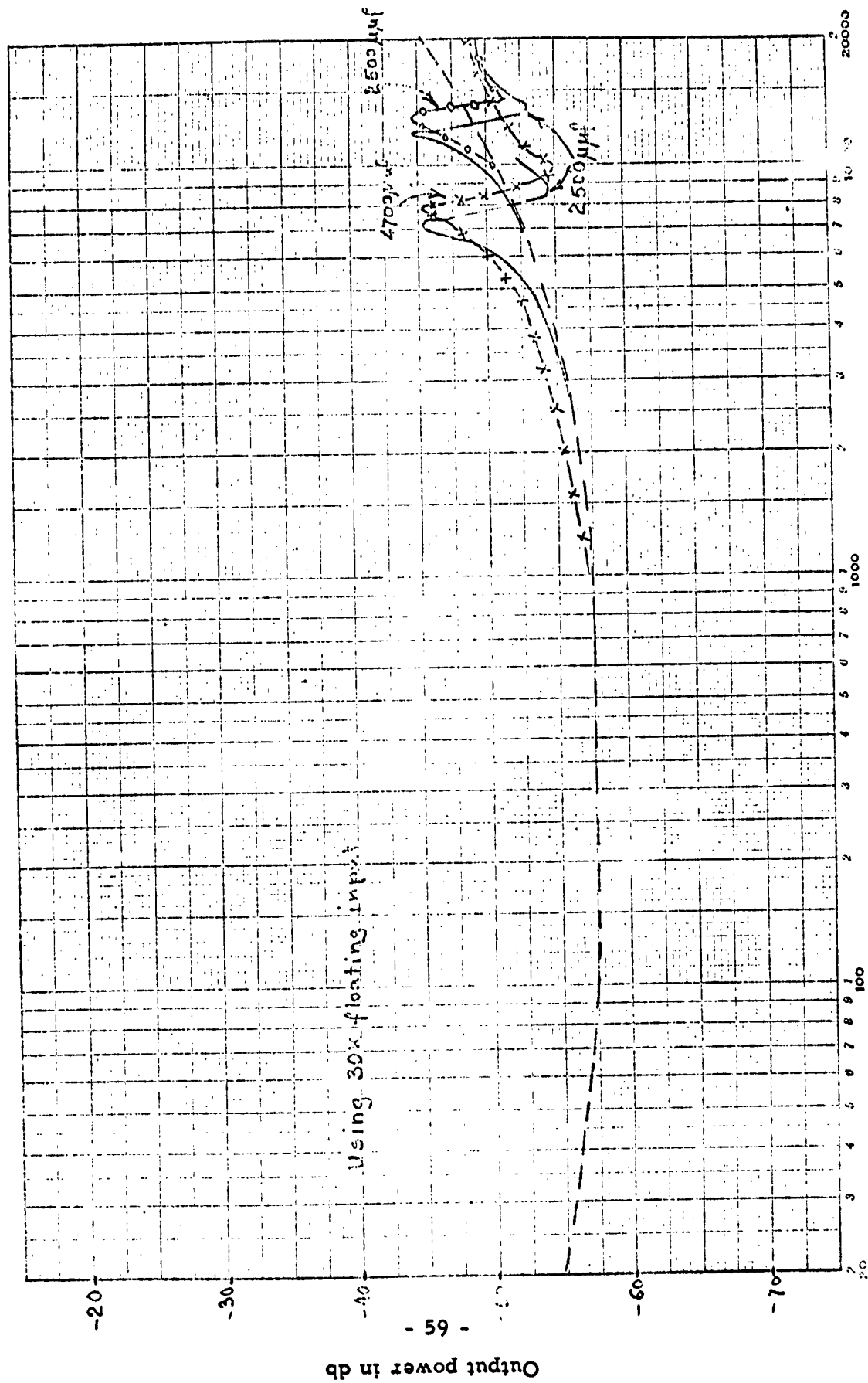
FIGURE 26

Equalization Curve (cf. Figure 9)

- 59 -

best values are shown in Figure 27. A combination of this feedback loop with R-C current feedback was inserted and tested. The R-C current feedback loop was inserted in the third and fourth stage cathode separately and both at the same time. None of these combinations resulted in the required equalization network.

Up to this point only conventional passive equalizing networks had been designed, built and tested and since none of them gave satisfacotry results it was deemed necessary that a more sophisticated approach was required. It was decided that the possibilities of variable inductors would be explored.

An Electrically-Variable Inductor Model PA-36 made by the Vari-L Company, Inc., was purchased, built into the equalizing circuit and tested.

An electrically-variable inductor is one in which the inductance can be controlled by a current or voltage. This is made in the form of a saturable reactor with two windings. One is called the signal, or tuned winding - corresponding to the A-C or load winding of a power handling saturable reactor: the other is the control winding and corresponds to the D-C winding. Usually variable inductors do not handle much power, but are used mainly for the control of resonant frequency in low level tuned circuits.

The Vari-L PA-36 was inserted between the plate of the fourth stage and the cathode of the third stage of the record amplifier

- 60 -

FREQUENCY IN CYCLES PER SECOND
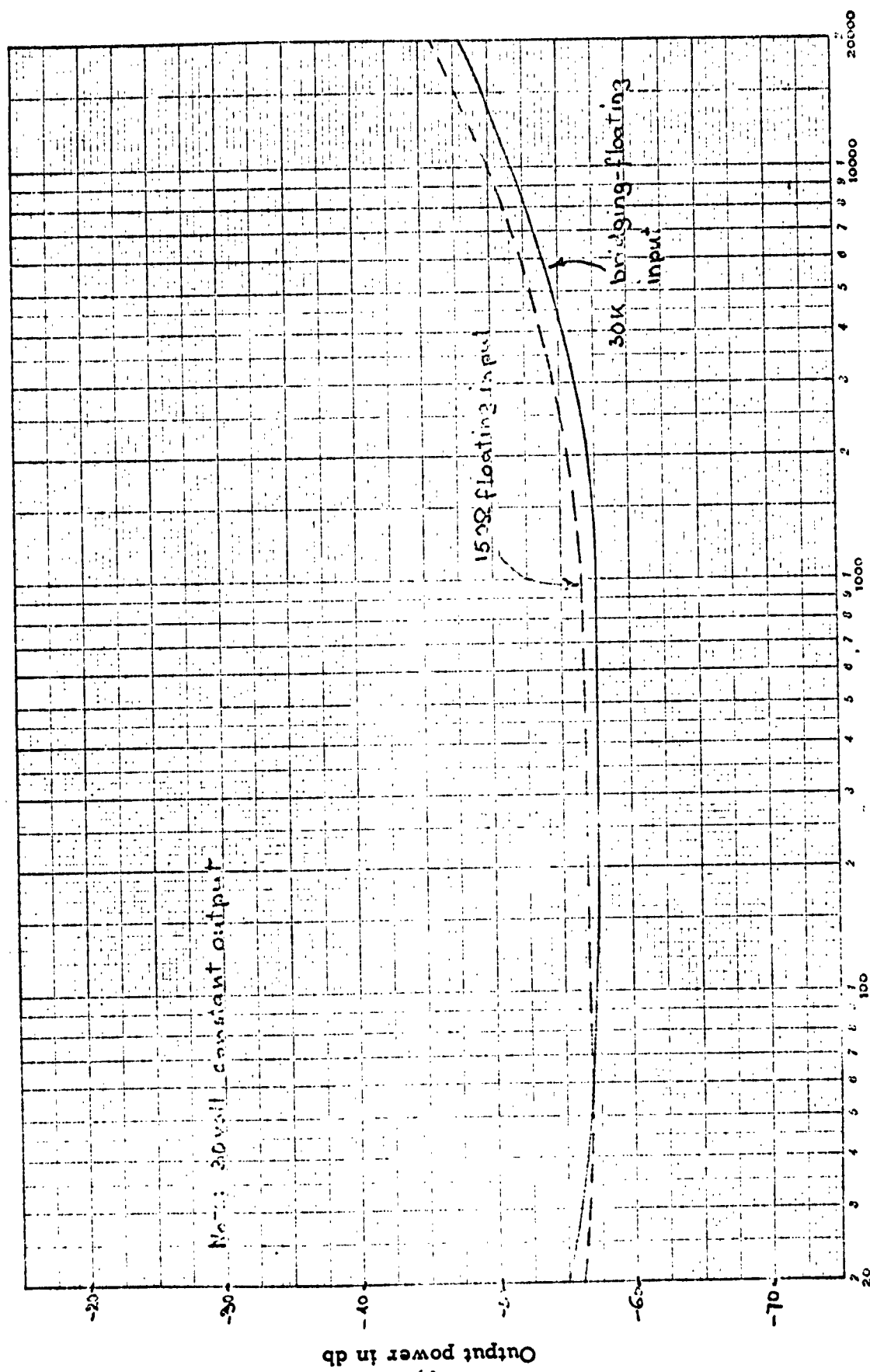
FIGURE 27

Equalization, Treble, Record Amplifier

as shown in Figure 28. The magnitude of the cathode bypass condenser is a function of this equalization network also.

The first, rough frequency response of this equalization circuit is shown on Figure 29. These response curves are far from the necessary results, but give a good indication that with further improved circuitry ideal equalization will be accomplished.
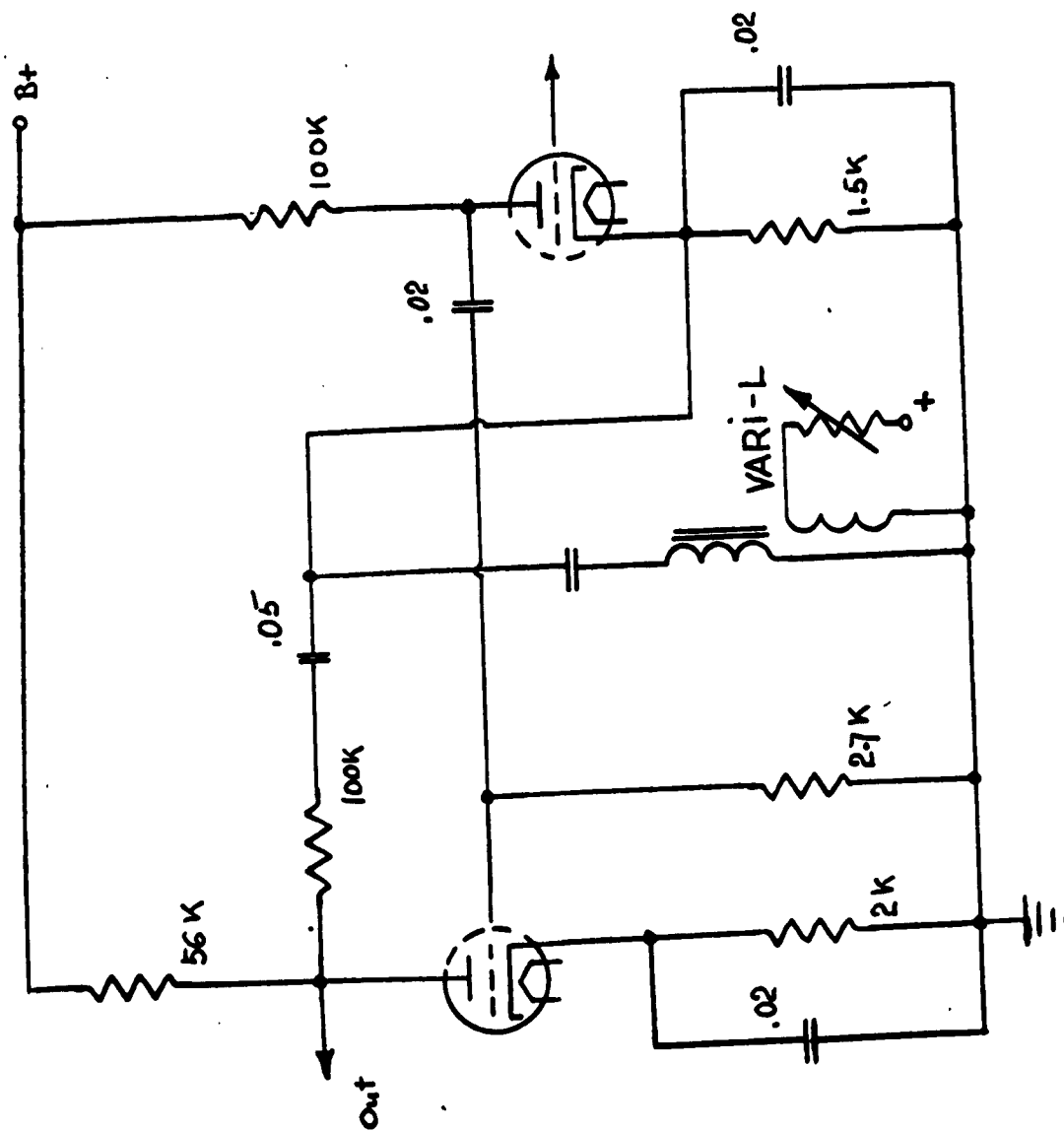
FIGURE 28

Equalizing Circuit with Vari-L

FREQUENCY IN CYCLES PER SECOND
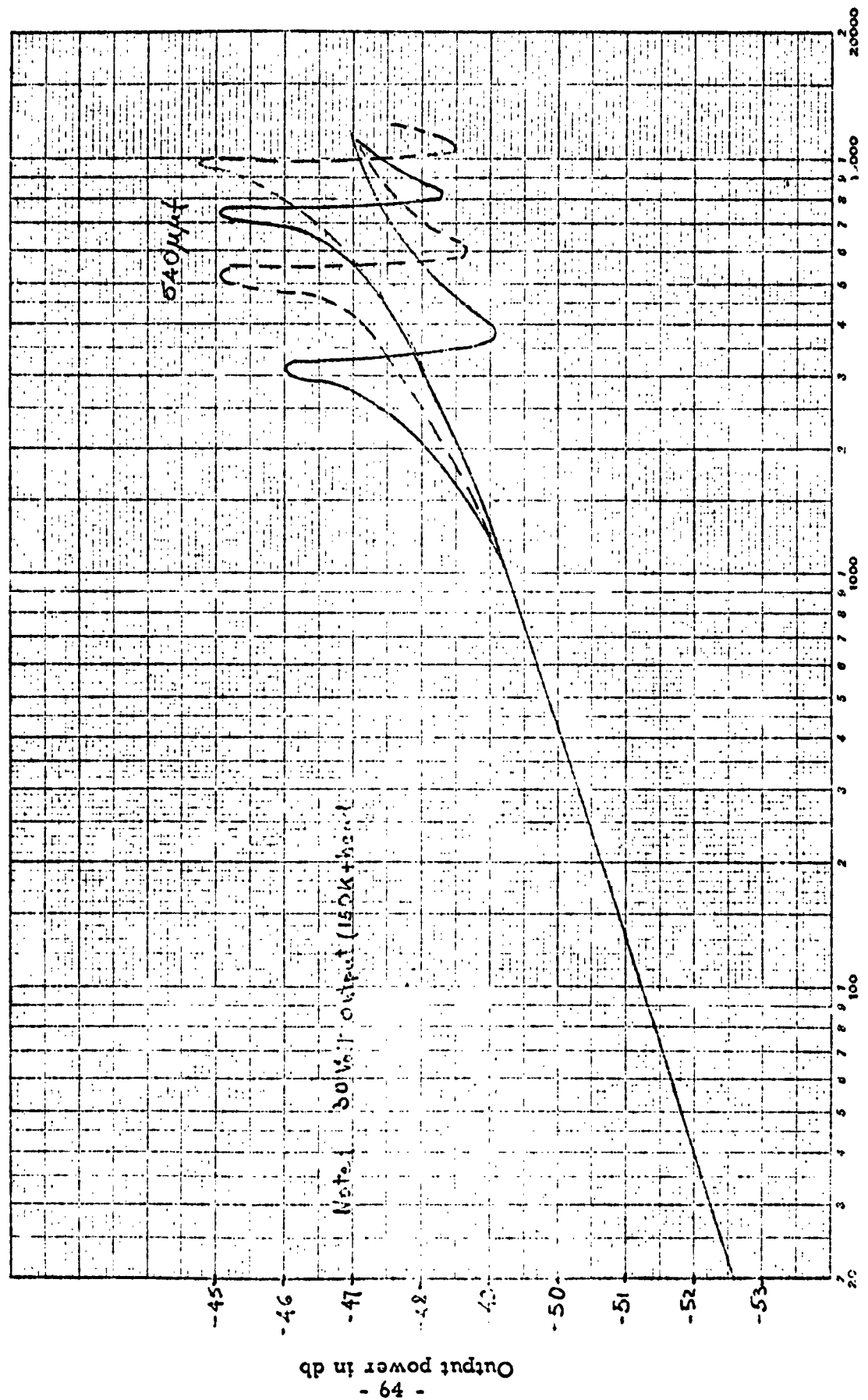
FIGURE 29

Equalization Curve with Vari-L (first)

Oscillator

The oscillator has a double function: provides bias current to the record head and erase current to the erase head.

The required bias and erase currents are given in the magnetic head specification sheet. For these specifications the Nortronics, Inc., Model T60-E bias oscillator transformer appeared well suited. Nortronics had a suggested record-erase circuit for this transformer using a 12AU7 double triode as oscillator in a multivibrator configuration as shown in Figure 30. The transformer has a high and a low impedance output windings. The voltage and power response curves of the transformer with the suggested circuit is shown in Figure 31 (unloaded) and Figure 32 (loaded). From these curves can be seen that neither the low nor the high impedance secondary windings give enough power to drive the heads for two channels. The transformer with this suggested circuit was originally contemplated for the one channel two-head system.

A modified circuit was used in order to retain the already purchased transformer to furnish enough power for the two-channel system. The new circuit is shown in Figure 33. This circuit is able to supply the necessary current for two-channel operation.

In Figure 33 the meter connection for bias current measurement is shown. This is not a permanent connection since the meter will be used for four different purposes. Switching arrangement for db-meter
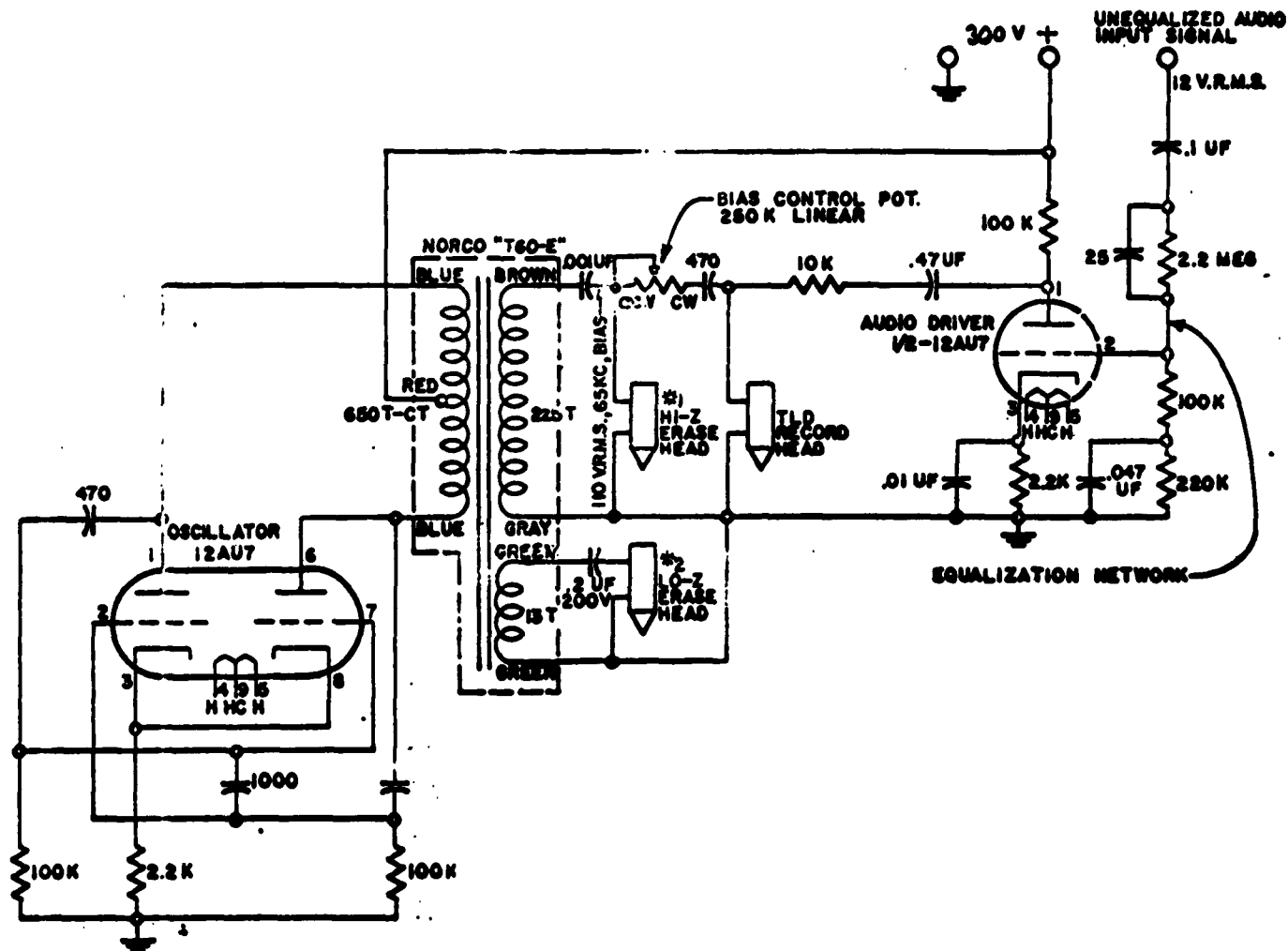
FIGURE 30

Typical Record-erase Circuit
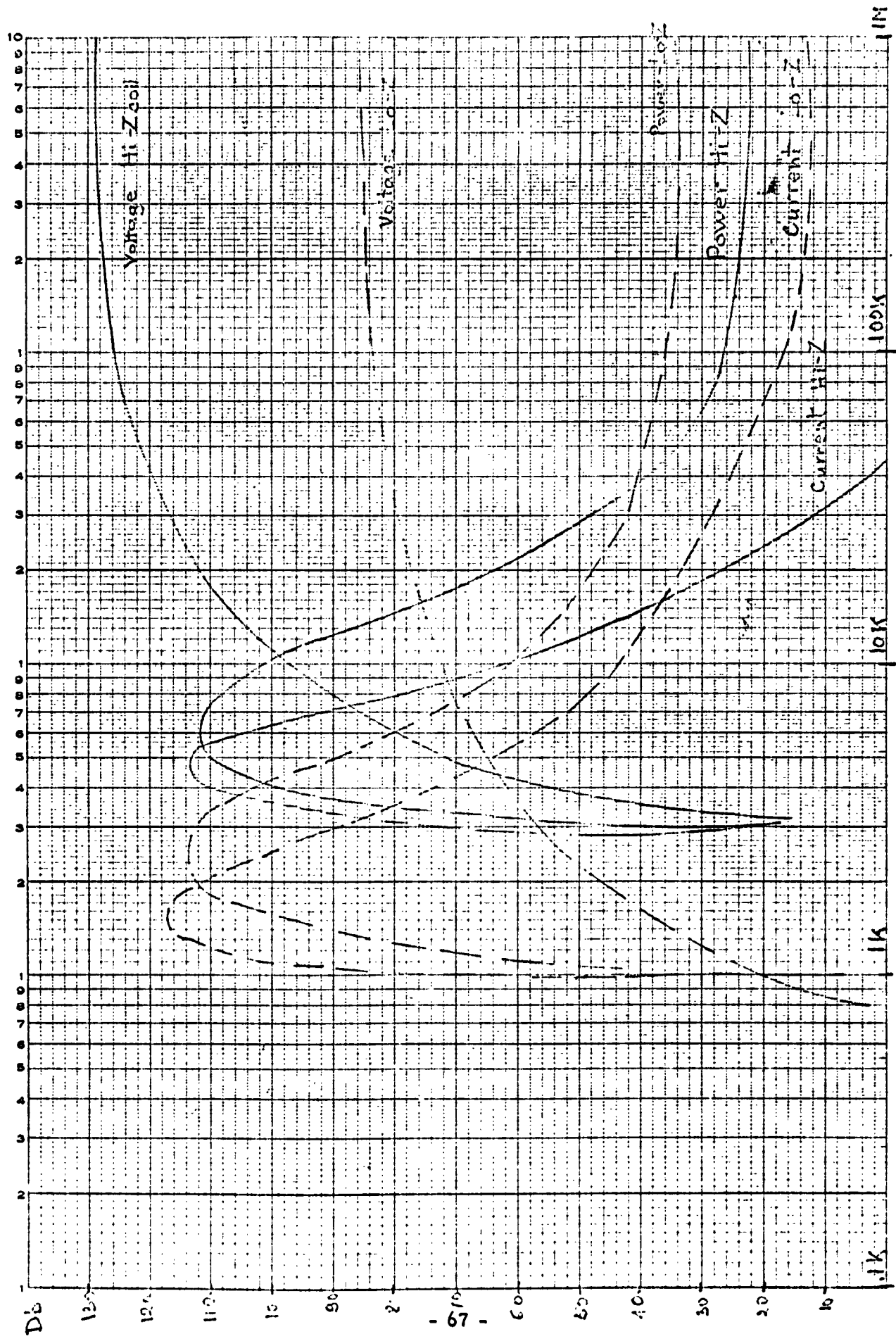
FIGURE 31
Bias Oscillator Curve (unloaded)
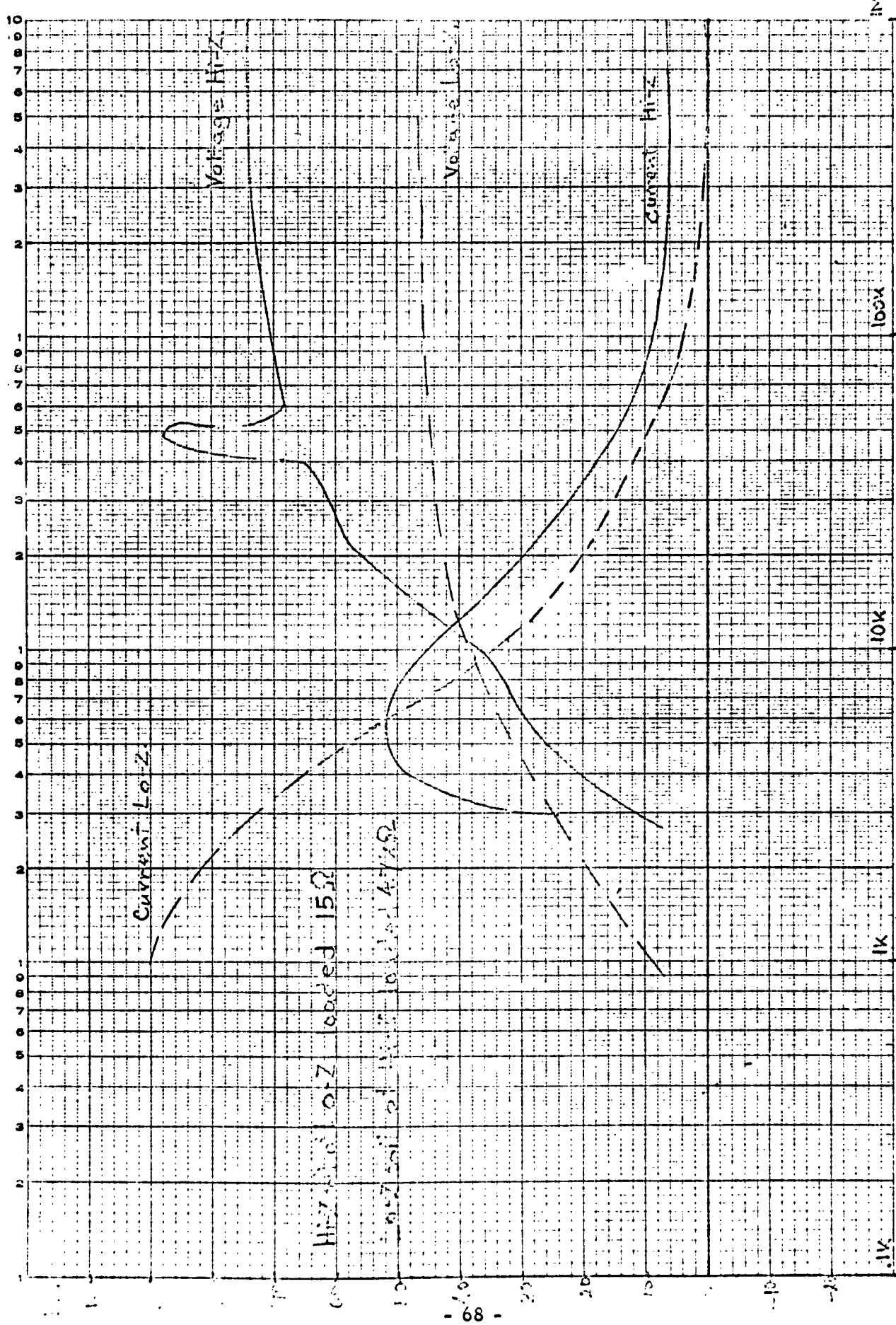
FIGURE 32
Bias Oscillator Response Curve (loaded)

FIGURE 33

Erase-and-bias Oscillator

selection is not shown.

For each of the so far reported frequency response measurement the test setup shown in Figure 17 was used.

Figure 34a and b is the photograph taken from the first three experimental test models. Figure 34b is the bottom view of the first-power amplifier. Figure 35 shows the top view of the power amplifier with the Chicago BOH-9 output transformer.

Figure 36 shows the complete amplifier for one channel in top view.

FIGURE 34a

FIGURE 34b

Photograph of the First Three Experimental Test Models
- 71 -

FIGURE 35

Photograph of the First-power Amplifier

- 72 -
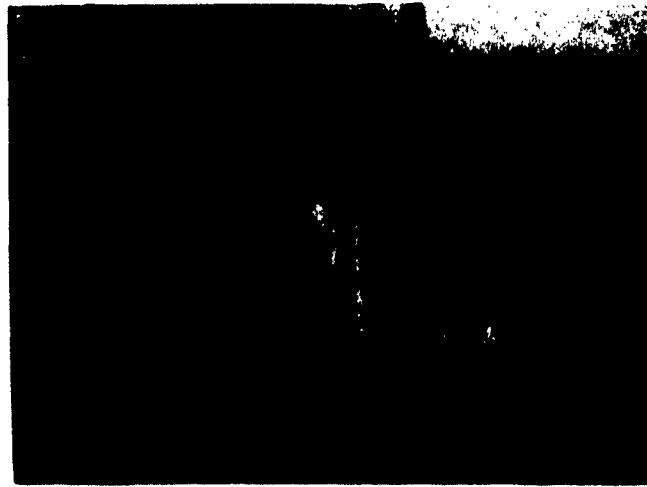
FIGURE 36

Photograph of the Complete Amplifier for One Channel

ELECTRONIC TAPE TRANSPORT CONTROL

The electronic control part of the tape transport is on a separate subchassis mounted under the front panel on the outer side of the U shaped frame (cf. description in the tape transport).

Initially an all push button control system was contemplated. During the preliminary design it was realized that the control of so many states of operation would require a large number of components, principally mostly relays. Therefore, a rotary switch was used to reduce this problem.

A rotating four-position switch was first used for the following operations:

> rewind
>
> stop
>
> play-record
>
> fast forward

At that time it was felt necessary to provide two braking modes according to the braking effect determined by the tape travel i.e., it was felt that the use of a differential brake was mandatory. By further design and experimentation, utilizing fully the basic design idea (i.e., feed reel control, cf. tape transport description) it was determined that this was not necessary. With the feed reel braking control completely satisfactory braking had been achieved.

A preliminary tape deck was set up and wired in mid-September. The approximate values of brake (clutch) current were determined. Operation of the deck appeared satisfactory. It was shown that the basic design concept was practical and useful.

The tape deck was demonstrated to Mr. Jack Unger on the 25 of September 1962. Conforming to his suggestions the following changes were made:

The main control switch was changed from four to the following five positions:

> rewind
> stop
> record - play
> stop
> fast forward

As a further result of the same discussion a pause function was added to the play-record position.

As presently wired the tape deck has three modes of operation in the record-play position:

Mode 1   - It plays back with the bias oscillator not operating

Mode 2   - It records with the bias-erase oscillator operating

Mode 3   - Pause or standby mode where the bias-erase oscil-

lator is operating but the tape is in stop position.

These latter two modes are operated with separate momentary action (push button) switches and self-holding relays.

An indicator light is used to indicate when the tape transport is in

- 75 -

the record or pause mode.   The indicator light is actuated by the

relay position.   A diagram of the electronic tape transport control

is shown in Figure 37.

Since two separate actions are required to turn on the bias-

erase oscillator, and the oscillator is killed by changing the main

control, little or no danger exists of accidental erasure.

The layout of the control is simplified to comply with the vi-

bration test requirement.

This control system efficiently performs all the required

functions of the tape transport without throwing loops or breaking the

tape.

Figure 38a and b shows a side view of the tape transport.

On Figure 38a, the electronic control part can be seen clearly.   Figure

39 shows the tape transport in a top view.
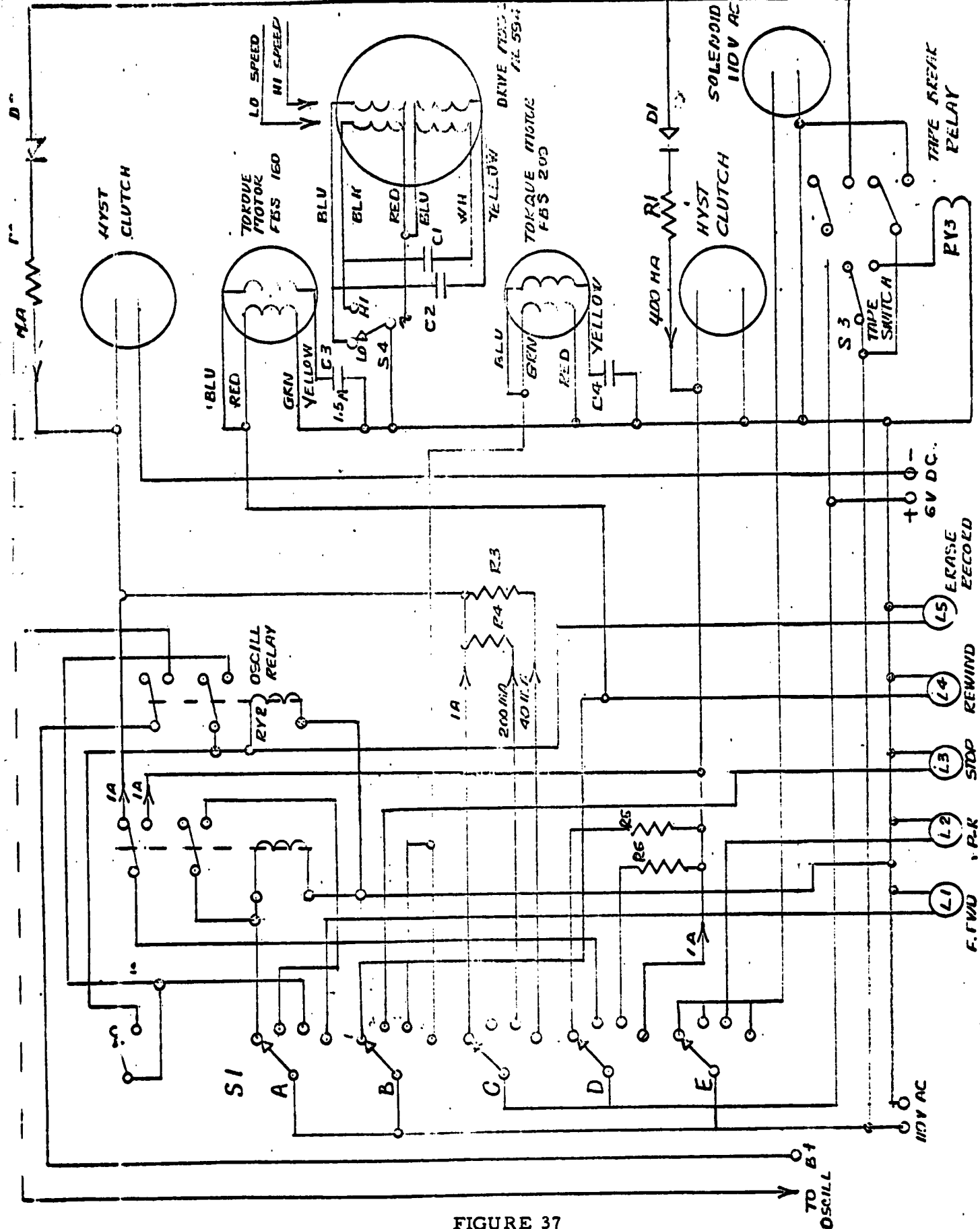
FIGURE 37

Diagram of the Electronic Tape Transport Control

- 77 -

FIGURE 38a

FIGURE 38b

Photograph of the Tape Transport (side views)

FIGURE 39

Photograph of the Tape Transport (top view)

- 79 -

TAPE TRANSPORT MECHANISM

A tape recorder consists of two basic parts mechanical (the tape transport mechanism), and elect)..ics.

This part of the report is concerned with the mechanical part, the term being used here in a broad sense to include everything other than electronics.

The primary function of the mechanical part of a magnetic tape recorder is to "handle" the magnetic tape during the recording, rewind, and playback operation. This "handling" procedure requires co-ordinated facilities for holding a reel of tape, feeding or unreeling the tape at a precisely controlled rate of speed past the record head, and then accumulating or re-reeling it after the recording process had been completed. A secondary requirement includes facilities for winding and rewinding tape (usually at a high speed). To accomplish all these required mechanical functions a complete array of mechanical elements is required.

An ideal transport mechanism would move the tape past the heads with an absolutely constant linear speed.

The tape is moved at the required speed as the result of being pinched between a motor-driven capstan and a spring actuated rubber roller, called the pressure roller. Guides keep the tape in line with the heads and prevents its weaving up and down.

The feed and take-up reels have a torque in opposite directions, though not with such a force as to rupture or stretch the tape. In motion, the tape moves not only against the torque of the supply reel but also with the torque of the take-up reel which tends to rotate at a speed considerably greater than that required to wind the tape. Tape would break if there were no provision for the reel to slip. Slippage is provided by using clutches or belts or, where the reels are directly motor driven, by choice of motors able to operate continuously at near stall (as a torque motor).

The rewind is performed by disengaging the pressure roller from the capstan, and a greater driving torque is applied to the feed reel than the take-up reel. On the other hand, to wind in the opposite direction, greater torque would be applied to the take-up reel.

This description concerns a conventional tape recorder.

The subject of transports merits an extensive discussion, but all that can be done here is to mention various other elements some of which are found only in the better mechanisms:

    (a)   brakes for bringing the reels to a rapid halt,

    (b)   means for changing the speed at which the tape is driven

    (c)   different head arrangement (convolute system)

    (d)   tape lift which spaces the tape slightly away from the

heads during rewind or forward wind to reduce head wear caused by the abrasive action of the tape,

(e) automatic shut-off of the transport if the tape breaks or runs out,

(f) a tape position indicator so that the user can readily locate any portion of a tape recording,

(g) Mu-metal covers for the heads to shield them from hum pick-up, particularly by the playback head.

DESIGN CONSIDERATIONS

A wide variety of arrangements are used to provide the torque for the reels in tape recorders. The aim is to provide a uniform forward-and-back tension while the capstan drives the tape. It must take-up the slack promptly with either an empty or a filled reel of tape, but must not exert so much force that it stretches or strains the tape beyond safe limits.

The tape moves at constant speed under the drive of the capstan, the rotational speed of the reel shafts will change by the some ratio while the reel is filling (since the outside to inside ratios are changing). The weight and the inertia will change by even wider ratios since the reels themselves are kept light.

Probably the simplest possible arrangement involves a friction brake for the supply reel and a slipping friction clutch for the take-up reel. The tape tension will then vary inversely with the radius of the tape stored on the reel, assuming the friction devices exert constant torque on the reel shaft.

For a precision recorder a torque motor may be used for each reel. These are usually single-phase capacitor induction motors, so wound that they will operate in the stalled position without over-heating. Their torque can be adjusted by changing the voltage applied to them.

When the supply power is removed from a torque motor, the rotor is able to rotate freely, and all tape tension is lost. Most arrangements using torque motors also include a solenoid-operated brake. The solenoid is operated by the same circuit as the torque motor with which it is associated. When the motor is turned on, the solenoid releases the brake and vice versa. For normal stop-start operation a simple brake would be sufficient. However, for fast rewinding (winding) of the reels a different arrangement is necessary. In order to stop a fast rewinding operation without throwing the tape into free loops about the machine, the brakes must be arranged so that the reel which is paying out the tape has the greater braking effort supplied to it.

Reed Research, Inc.'s. K-3 Variable Speed Magnetic Tape Transcriber utilized a similar tape transport and brake arrangement. The experience gained from this machine brought out several short comings of this system, that should be eliminated from this design. The main difficulty was caused by a take-up loop at high tape speeds, therefore, the design effort is concentrated toward the elimination of such loops.

The most critical combination in the braking system is that a heavily loaded pay-out reel must stop at the same time as the lightly loaded take-up reel. With the brakes adjusted for this condition, the tape should not be strained when stopping with a lightly loaded pay-out reel and a heavily loaded take-up reel. These are usually the limiting

combinations which must be taken into account when determining the maximum tape load and minimum tape strength.

For a mathematical solution, we may make the following assumptions:

(1) The length of the tape between the reels is constant during braking.

(2) No elasticity in tape

(3) Radius does not change during the braking

(4) Constant torque braking i.e., braking torque is not a function of reel load.

The angular acceleration of one reel caused by a torque is given by

$$I \cdot \omega = I \ddot{\Theta} = I\alpha \tag{1}$$

where
- I = moment of inertia
- α = angular acceleration
- T = torque
- ω = angular velocity
- $\dot{\omega}$ = first derivative of angular velocity
- Θ = angle
- $\dot{\Theta}$ = first derivative of angle
- $\ddot{\Theta}$ = second derivative of angle

In the actual tape transport system there are two reels as shown
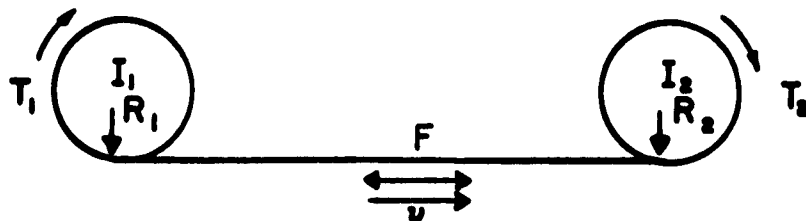
where T_1, T_2 = braking torque

         F = tension force in tape

         V   = velocity of the tape

         R_1, R_2 = tape load radius

Substituting for each reel into Equation (1)

$$T_1 - R_1 F = I_1 \ddot{\theta}_1 \tag{2}$$

and

$$T_2 + R_2 F = I_2 \ddot{\theta}_2 \tag{3}$$

Using assumptions Numbers 1 and 2, the rate of feed from reel (1) equals the amount taken up by reel (2) as given by

$$R_1 \dot{\theta}_1 = R_2 \dot{\theta}_2 \tag{4}$$

Taking the derivitives of Equation (4)

$$R_1 \ddot{\theta}_1 = R_2 \ddot{\theta}_2 \tag{5}$$

Substituting into equation (5) for θ_1 and θ_2 from Equations (2) and (3)

$$\frac{R_1 T_1 - R_1^2 F}{I_1} = \frac{R_2 T_2 + R_2^2 F}{I_2} \tag{6}$$

The moment of inertia (I) is composed of two parts; one constant I_c, and the second a function of R. (I(R)).

$$I_1 \quad I_o + I(R) \tag{7}$$

Where

$$I(R) = \frac{2 \, \Pi \, t}{4} \, \rho \, (R^4 - R_{min}^4) \tag{8}$$

In our case (7 inch reels) $I \quad (R)_{max} = I_c$

or

$$I = \frac{\Pi \, t \, \rho}{2} \left[(3.5)^4 - (1)^4 \right] + \frac{\pi t \, \rho}{2} \left[(R_1)^4 - (1)^4 \right] \tag{9}$$

It is seen that only a small error is incurred by discarding the $(1)^4$ terms then

$$I_1 = \frac{\pi \, t \, \rho}{2} \left[(3.5)^4 + (R)^4 \right] \tag{10}$$

and

$$I_2 = \frac{\pi \, t \, \rho}{2} \left[(3.5)^4 + (R_2)^4 \right] \tag{11}$$

Substituting Equations (10) and (11) into Equation (6) and simplifying.

$$\frac{R_1 \, T_1 - R_1^2 \, F}{150 + (R_1)^4} = \frac{R_2 \, T_2 - R_2^2 \, F}{150 + (R_2)^4} \tag{12}$$

One might consider it ideal if the tape transported no tension
i.e., $F = 0$. Under this condition Equation (12) becomes

$$T_1 = \frac{R_2 \, (150 + R_1^4)}{R_1 \, (150 + R_2^4)} \, T_2 \qquad (13)$$

Let $R_1 = 1$; $R_2 = 3.5$, then

$$T_1 = 1.75 \, T_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Let $R_1 = 3.5$; $R_2 = 1$

$$T_1 = .57 \, T_2 \qquad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Due to the symmetry of the system one sees that for rewind T_1
and T_2 are interchanged.

Equations (14) and (15) show that no general solution exist except
for $T_1 = T_2 = 0$ or ∞

As $T \longrightarrow \infty$ a solution exists if the tape is elastic. This solu-
tion is discarded as impractical because the brake must be applied simul-
taneously or nearly so, causing a serious timing problem particularly .
after wear has occurred.

The other assumptions must be investigated to find a practical
solution.

The only additional assumption that may be violated is that $F = 0$. The relationship given in Equation (12) must be investigated.

Assuming full 7-inch reels, a numerical investigation shows that if $T_2 = 0$, F is maximum and varies from

$$F = .1395 \, T_1 \quad to \quad F = .2458 \, T_1$$

Also to prevent tape spill

$$T_2 \leq .576 \, T_1$$

By applying $T_2 = .576 \, T_1$ the maximum reduction of 30 percent in tension force (F) was computed. This relatively small reduction in tape tension did not seem to warrant the added complexity and reduction in reliability incurred by braking both reels. Therefore, for simplicity of construction and increased reliability, the design will use braking on the feeding reel only.

In setting up this equation the fraction forces were disregarded.

From the solution of the preceding equation a practical solution can be designed where the transmitted tape itself brakes take-up reel. Tape tension must be limited to some safe value. The transport system to be described operated in this fashion.

The tape transport described in our original proposal used a ball-and-disc integrator (later described) driving the capstan and the take-up

reel. Tape tension at the heads is maintained by a hysteresis brake on the feed reel. Shuttle modes are accomplished by separate motors directly coupled to the feed and take-up reels. Back-to-back sprag clutches isolated the integrator output from the take-up reel during the shuttle mode.

Shortly after the start of the project, it was determined that the integrator output torque would be insufficient (actually marginal) to both meter the tape (at the capstan) and drive the take-up reel. It was thus necessary to drive the take-up reel in the play-record mode by means of a separate motor.

The final tape drive consisted of two hysteresis clutches, two sprag clutches, two reel motors, and, of course, the integrator and its associated motor. The block diagram of this transport is shown in Figure 40. It will be seen that this is, as far as we know, a new and novel design possibly deserving protection under the PATENT SYSTEM. It is believed that the novelty lies chiefly in the combination of hysteresis clutch, overrunning clutch and motor providing a controllable drive and braking system. The details of this system are described in the following system.

The sprag clutches are used between the reel motors and the motor side of the clutches. Their action is to prevent rotation of the motor side of the clutches in the unwinding direction, while permitting free running in the winding direction. (For this sense the winding direction of each reel is that direction of rotation which fills the reel in

- 90
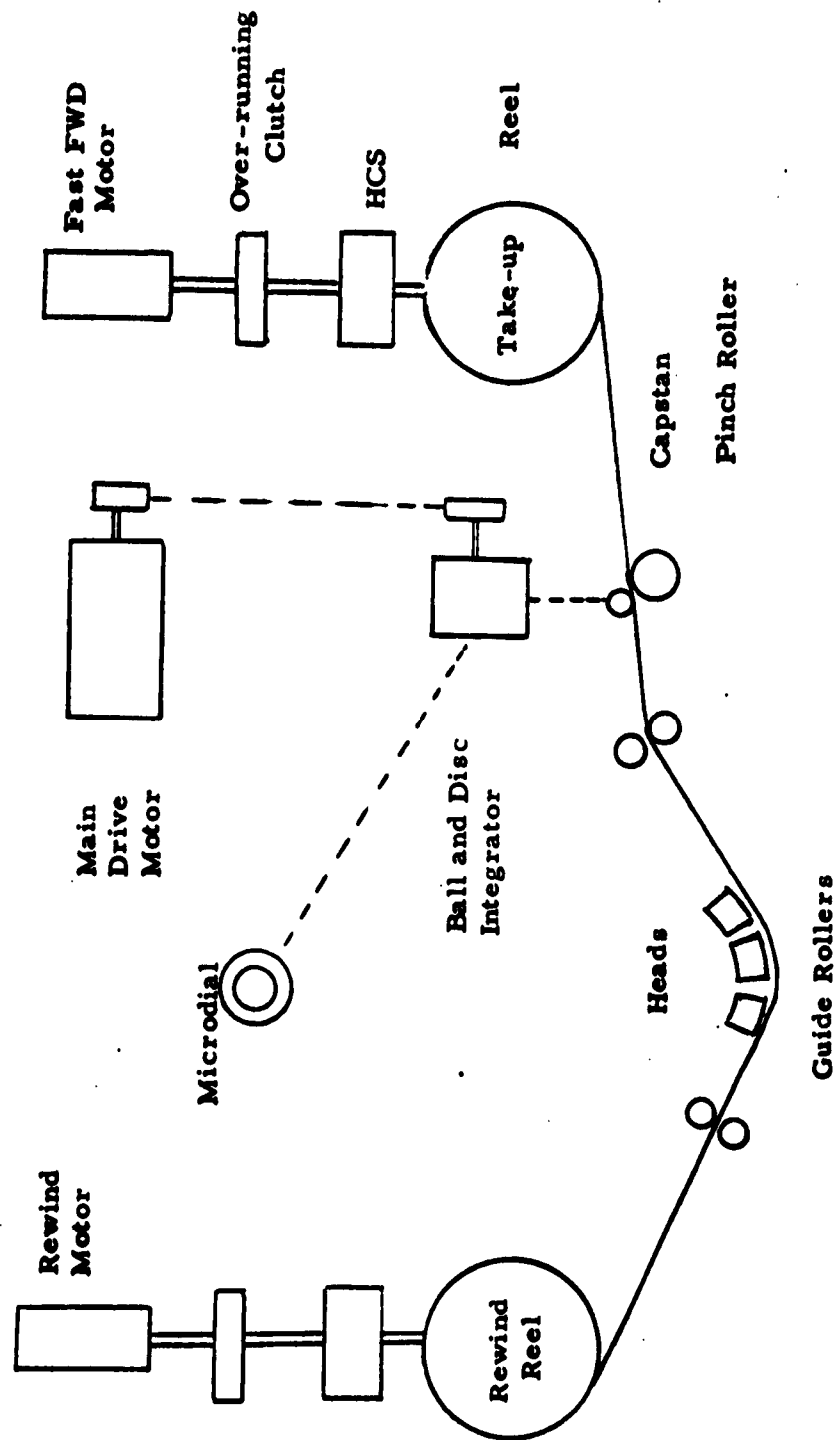
FIGURE 40

Block Diagram of Tape Transport

question.)

This arrangement permits the reels to be uncoupled, loosely, coupled, or tightly coupled to the motor shaft, which shaft is free to turn in one direction only

The sprag clutches thus provide differential braking, when required; the hysteresis clutches control the tape tension at all times, and the reel motors provide a source of power to whichever reel is taking up tape.

The Magtrol HCS 200 stationary coil hysteresis clutch was selected. This is a new design which eliminates the sometimes trouble-some characteristics of slip rings and brushes.

Continuously Variable Speed

The heart of the continuously variable system is a Ball-and-Disc Integrator made by the Reflectone Corporation as shown in Figure 41. This is a purely mechanical device used to obtain the integration of one variable with respect to other.

For a given increment of rotation $\underline{A}$ the roller will turn an amount $\underline{B}$ proportional to this motion and the distance of the balls from the center of the disc. For a given disc speed the rotation of the out-put roller decreases as the balls are moved toward the center and reverse as they cross the center. The above relationship can be expressed by the following equation:

$$B = KyA$$

where

K   _ the (mechanical constant of the integrator)

- 92 -

$\int y\, dx$

y

dx
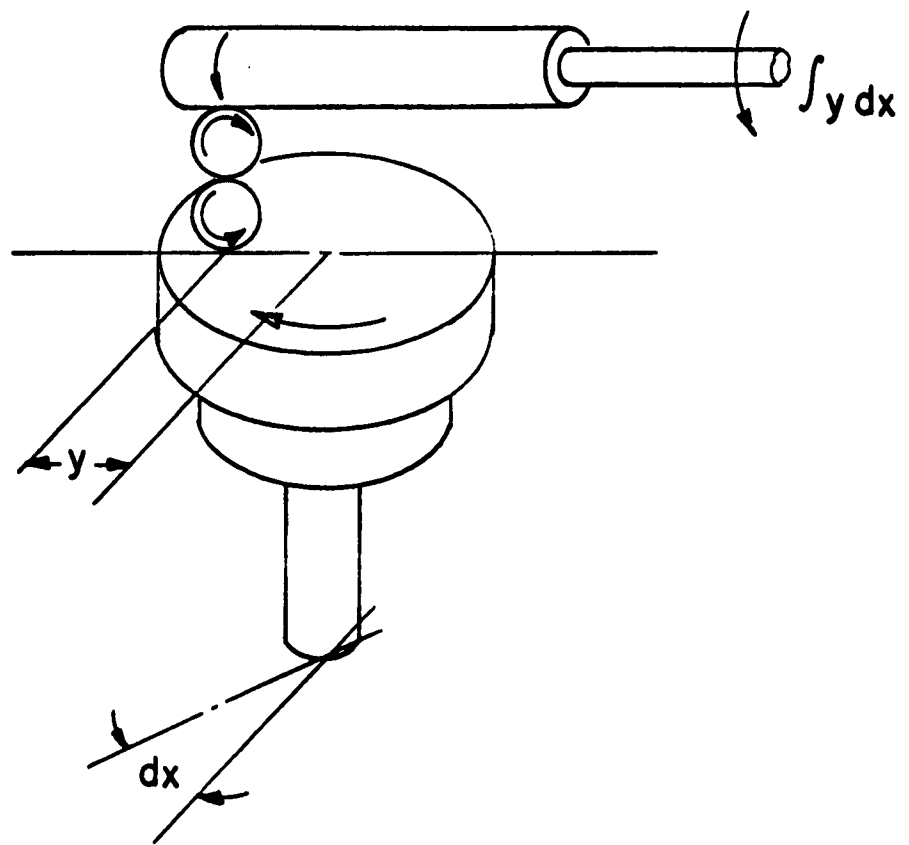
FIGURE 41

Ball-and-disc Integrator

The speed is manually adjusted by a microdial, with vernier readings from 1 to 1,000 which will be calibrated directly into tape speed. The dial is coupled, by a chain link, to the integrator. The power input to the integrator is from a hysteresis synchronous motor.

Elinco's (Electric Indicator Company) Model ALHJRN-594 Dual Speed Hysteresis Synchronous Motor had been chosen. This motor was chosen since this company is specialized in the hysteresis synchronous motors, they have more published data than other companies (we know of), and the required two speeds were available.

A two-speed motor was chosen to comply with the peculiarities of the ball-and-disc integrator. The ball-and-disc integrator should work in its mid and outer range for best results. Therefore, we should find two over-lapping range of speed that will avoid use of the integrator near its center. (A stop within the integrator was adjusted to prevent travel of the balls to the center.)

The theoretical minimum shift would be the square root of the maximum speed ratio required (20 inches per second and 1 inch per second). The 600-rpm and 3,600 rpm motor gives a ratio of 1:6 which was judged suitable.

The pulley ratio between the motor and integrator is defined by the maximum speed of the integrator for any given motor, while the capstan size is determined by the maximum motor speed, integrator speed, and the required tape speed.

- 94 -

The capstan is the most determinative element in the entire drive system. Therefore, for the best result, there should be a minimum number of driving elem... . between the motor and capstan. Any mechanical device in this drive system which has eccentricities, wobbles, loose bearings, irregular belts etc., will ultimately result in instantaneous speed variations of the tape.

For maximum simplicity of design involving a minimum number of mechanical linkages the three motor drive system is used. This eliminates the various switching, belt dives and linkages and minimizes the sensitivity toward vibration. This system easily furnishes the required power for each of the three basic tape movements required.

Head Arrangement

Tape recorders have at least two heads; an erase head for removing previous recordings and a head used for both record and playback. In this project we use three heads. Beside the erase head, the second head is used for recording only, the third is used for playback and monitor (instantaneous playback while recording).

It is important that no significant space exist between the head gap and tape. Separation between the head gap and tape results in a substantial loss of high-frequency response. Intermittent variations in pressure result in changes of amplitude. To insure proper contact two different methods may be used.

The pressure pad is used to exert a uniform pressure on tape to insure good contact and unwrinkle minor transverse irregularities in the tape. The pressure pad introduces more friction, more wear on tape and more moving parts which add to the vibration sensitivity.

The other method uses tension in the tape and a wrap angle to form a path such that the tape is forced to follow the contour of the head without the use of a pressure pad. With this system, using hyperbolically shaped heads, the heads can be used in a straight line tape path but guiding posts are required between the heads to force the tape to follow tht wrap angle of the head. Such posts can be designed but this arrangement is undesirable from the point of view of vibration sensitivity.

To eliminate these posts the convolute tape path was chosen. This convolute tape path provides the necessary tension of the tape against the heads.

Convolute tape path is such that the tape is folded around the heads in such a way that the tape is forced to follow the contour of the heads without using any pressure pad.

- 96 -

CONSTRUCTION OF THE TAPE TRANSPORT

Basically the tape transport is built around a front panel

and a U shaped frame made of 3/16 aluminum plates. The assembly

Front panel

U shaped frame
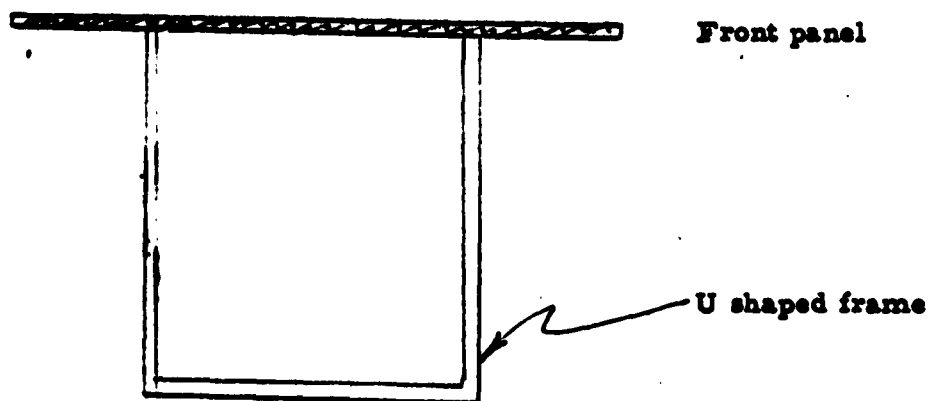
FIGURE 42

Basic Frame

is reinforced with 3/4 x 3/4 x 1/8 aluminum angles.

This frame contains:

(a)   2 power trains on both sides . One for each reel,

(b)   adapter assembly which fits into the front panel

(c)   drive system with main drive motor, ball and disc

integrator and drive pulleys.

(d)   electrical control panel

(e)   audio subchassis

POWER TRAINS

Important features of the power trains:

Reel hubs with reel lock

Hysteresis clutch

Over-running clutches

a-c induction motors

The last three components are mounted on the back part of the sides of the U-shaped frame with socket head cap screws and self-locking washers. These socket head cap screws are used in order to have easy access to the power train parts. Since the frame is aluminum no tapped holes are used, to avoid the requirement of using helicoil inserts in the holes.

The hysteresis clutch and the over-running clutch are enclosed in separate aluminum housings. The latter housing has provision for the reel motor mounting. The housing further serves as shielding and heat-sink.

There are three shaft extensions in each power train to provide a unified shaft size for the flexible coupling.

Two flexible couplings are used in each power track to take care of the alignment problem. The flexible couplings are made by Lord Manufacturing Company (Model J-1211-1-1). These flexible couplings

permit misalignment of ± 1/32-inch parallel and 2° angular. Its basic construction consist of two steel hubs and a flexing element which is made of an environmental resistant elastomer.

Under the reel hub a nylon bushing is used, since this does not propose any environmental trouble and is relatively inexpensive.

The main drive motor, (hysteresis synchronous) is installed in the mid-compartment of the U-shaped frame with four socket head cap screws and lock nuts. The ball-and-disk integrator is mounted in the same compartment, but above the drive motor with four socket head cap screws and lock washers. The shaft of the main motor and the input shaft of the ball-and-disk integrator protrude to the other side of the frame through large cutouts, hence no bushings are needed. Each shaft has a pulley for the drive belts. The pulleys have large flanges to prevent the belt from slipping off the pulleys during extensive vibration.

The drive belt is an impregnated cloth belt. Constant tension of the drive belt is maintained by a nylon pulley with spring tension.

On the other outer sides of the U-shaped frame the electronic tape transport control assembly is mounted. (cf. Figure 38a.)

FRONT PANEL

The front panel holds the two reel hubs, the tapeguides, pulleys, the capstan and the tape deck controls. (cf. Figure 39.)

The adapter assembly, which fits into the front panel cutout has on its top:

> 3 heads
>
> 4 guide rollers
>
> 1 pinch roller assembly
>
> 1 arm assembly

Underneath the plate is the audio subchassis. The bottom end of the audio subchassis carries cannon plug and connects the tape transport to the audio amplifier.

The heads are mounted for a convolute tape threading as previously described. The arm assembly provides for removal of the tape from the heads during rewind, fast forward, and stop.

CONCLUSION

From the report we can draw the conclusion that in the change from single channel to dual channel and from the two-head system to the three-head system a considerable amount of special effort was made to comply with the revised contract requirement.

We have demonstrated the dual-channel construction. One channel has been built since the other channel is identical. Signal-to-noise ratio requirements need more work.

We have demonstrated the tape transport mechanism which is in good operating condition. Flutter and wow elimination is causing some difficulty.

PROGRAM FOR THE NEXT INTERVAL

In the next interval, phase three, the prototype test and final design will be finished; and phase four, procurement and manufacture, of three units should be complete.

IDENTIFICATION OF PERSONNEL

The following technical persons are directly assigned to

the contract and took part in the work covered by this report:

Donald E. Reed, B.S. in E.E., Senior Electrical Engineer, Project Engineer. Work performed 471 hours.

John L. Toth, B.E., Electrical Engineer, Assistant Project Engineer. Work performed 507 hours.

Thomas Lanyi, B.S., Associate Engineer in Electronics. Work performed 430 hours.

John L. Baldwin, M.S.M.E., Senior Mechanical Engineer. Work performed 220 hours.

Ralph E. Walker, Designer. Work performed 480 hours.

A brief description of the background of each of the above

listed persons can be found in the following pages:

DONALD E. REED

Mr. Reed has 12 years of experience in electrical engineering and related fields, including electronics, instrumentation, optics, photography, photometry, and illumination, He has an exceptionally good background in control systems, servos, high speed optical scanners, and printed circuit boards and components.

EDUCATION:

Union College, 1950, B.S. in E. E.

EXPERIENCE:

National Bureau of Standards, Electrical Engineer
Reed Research Inc.

DESIGNED AND DEVELOPED:

Servo Control System for Constant Energy Spectrosensitometer
Servo Control System for Pressure Simulator
Light Source for Rectifying Projector
Special Stereo Camera
Electronic Control System for Orthographic Photogrammetric
  Printer
Optical and Lighting System for 70 mm Stereo-viewer
Special Scanning Camera
High Speed Optical Scanning Device for Reduction of Graphic Data
Electronic Control System for High Speed Wire Cloth Loom
Miniature High G Latching Relay

INVESTIGATED:

Advanced Techniques for Printed Circuit Board and Components
High Speed Mail Handling Techniques and Equipment
Lamp and Lens Design of Visibility Measuring Devices
Spectral Properties of Photosensitive Materials and Light Sources
Atmospheric Optics
Airport and Aircraft Lighting and Landing Devices
Magnetic Materials Applications in Microminiature Devices

TECHNICAL SOCIETIES:

Institute of Radio Engineers
Society of Photographic Scientists and Engineers
Society of Motion Picture and Television Engineers

JOHN TOTH

Senior Electronics Engineer   SECRET Clearance

Mr. Toth, a native of Hungary, has an extensive background of education and experience both in Europe and in the United States. He has designed numerous items of electronic test equipment, photoelectric instruments, and communications equipment.

EDUCATION:

Technical University of Budapest (Hungary), 1951, Diplom
Engenieur (Equivalent to U.S. degree of B.S. in E.E.)

EXPERIENCE:

E.M.G. (Electronic Measuring Gear), Budapest, Hungary
Laboratory Engineer
Hiradastechnika, KTSZ, Budapest, Hungary
Chief Engineer, Prototype Laboratory
Reed Research Inc.
Electronics Engineer
Nems-Clarke, Inc.
Electronics Engineer
Space Components Inc.

DESIGNED AND DEVELOPED:

Heterodyne frequency meter
Direct reading frequency meter
Electric photoflash
LVDT displacement indicators
Distance translators
Distance integrators
VHF transmitters
Voice frequency control circuits

INVESTIGATED:

Magnetically activated environmental switch (FluxLink)
Magnetically activated environmental relay

THOMAS LANYI

Associate Engineer (Electronics)   SECRET Clearance

PRINTED CIRCUITS   TEST EQUIPMENT
ELECTRONIC CONTROL CIRCUITS   TRANSISTORS
TELEVISION   AUDIO DESIGN
COLOR TELEVISION

EDUCATION:

B.S. "Ludovika" Royal Hungarian Military Academy
George Washington University - School of Engineering
    and Applied Science. Expect to graduate from B.E.E., June
    1963

EXPERIENCE: Total years Eight

Staff Officer, Communication, Armored Corps, Hungarian Army
Technical Manager, Electronic Dept., The Hecht Company
Associate Engineer (Electronics), Reed Research, Inc.

DESIGNED AND DEVELOPED: (in whole or in part)

Closed circuit TV for display
Miniature amplifier for sound detection
Custom HiFi
Chart Reader
M-6A Educorder dual tape recorder
K-3 Continuously variable tape reproducer
Transistorizing the "Diotron" true rms voltmeter
Failure alarm control for wire loom
Transistorized d-c amplifier

INVESTIGATED:

Printed circuitry
Solar power terrestrial application
Digital computer use to study television signal redundance with
    third order probability distribution
Digital Displays
High frequency transistorized video amplifier

INSTRUCTED:

Basic Electricity
Test Equipment Techniques and Applications

JOHN L. BALDWIN

Senior Mechanical Engineer   SECRET Clearance

     Mr. Baldwin has broad experience, both theoretical and practical, in mechanical engineering, with special emphasis on machine design and mechanisms. He also has experience in hydrodynamics, field and laboratory testing of many types of equipment, and structural design. Mr. Baldwin is a registered professional engineer.

EDUCATION:

University of Maryland, 1952, B.S.M.E.
University of Maryland, 1956, M.S.M.E.
   Additional Graduate Courses in Aeronautical Engineering
   and Mathematics

EXPERIENCE:

National Bureau of Standards, Student Aide
David Taylor Model Basin, Junior Engineer
Naval Ordnance Laboratory, Project Engineer
Reed Research Inc.

DESIGNED AND DEVELOPED, In Whole or in Part:

Inertia Timer
Various Parachute Containers
Aerodynamic Stabilizing Fins
Subsonic Wind Tunnel Models
High Frequency Accelerometers
Discriminating Accelerometers (low frequency)
Ball Lock Release Devices
Air Gun Diaphrams
Explosive Drivers
Manual Tracking Mount
Underwater Parachute Test System
Level Track Rocket Sleds
Free Flight Rocket Sleds (Motors burn out before launch)
Explosive Bolts
Gun Mount for Model Launcher
Lighting and Camera Housings and Supports for Underwater
   Photography
Transonic Free Fall Test System

John L. Baldwin

DESIGNED AND DEVELOPED (con't.)

        Supersonic Free Fall Rocket Boost Test System
        Components of Several Aircraft Delivered Weapons
        Metal Shipping Containers
        Structures for Test Sets
        Missile Handling Equipment

INVESTIGATED:

        Aerodynamic and Hydrodynamic Trajectories
        Aerodynamic Properties of Various Shapes
        Prestressed Beam Columns

INVENTED:

        Shape and Construction of an Aerodynamic Fin
        Various Mechanisms Used in an Aerial Delivery System

AUTHORED:

        Report on the Effect of Various Design Parameters High
            Drag Trajectories
        Report on Water Impact Forces and Underwater Trajec-
            tories of Various Shapes
        Reports of Various Field and Laboratory Tests
        Reports of Various Wind Tunnel Tests

TECHNICAL SOCIETIES:

        American Society of Mechanical Engineers
        Tau Beta Pi

RALPH E. WALKER

Designer   **SECRET Clearance**

Mr. Walker has more than 14 years of experience in such fields as hydrography, mechanisms, ordnance, topography, and packaging. He has designed and developed reusable ordnance shipping containers, and also has designed missile handling equipment and stowage systems, as well as containers for various commercial items.

EDUCATION:

Graduate, Class A and B Drafting School, U.S. Navy
George Washington University (attending Engineering School)

EXPERIENCE:

U. S. Navy, Draftsman
U. S. Navy, Ordnance Designer
Reed Research Inc.

DESIGNED AND DEVELOPED:

Terrier Dolly
Stacking Cradle for Talos Missile
Handling Band for Talos Missile
Talos Handling Dolly Components
Loading Rabbit for SS 580 Class Submarine
Missile Handling Equipment for NAMC
Cartridge Cases
16" Exp. Nuclear Projectile
Lightweight Jacks

INVESTIGATED:

Fixed Ammunition
Spiral Wrap Cartridge Case
30-mm. Exp. Projectile
Towing Dolly for Terrier Missile
Existing Documentation on All Naval Missile Systems
    pertaining to preservation, packaging, packing,
    handling and shipping

INSTRUCTED:

Drafting

DISTRIBUTION LIST

CONTRACT NO: DA 36-039 SC-89067   TASK NO: 3N32-01-001-03-05

No. of Copies

OASD (R&E), Room 3E1065
ATTN: Technical Library
The Pentagon
Washington 25, D. C.   1

Chief of Research and Development
OCS, Department of the Army
Washington 25, D. C.   1

Commanding General
U. S. Army Electronics Command
ATTN: AMSEL-AD
Fort Monmouth, New Jersey   3

Director, U. S. Naval Research Laboratory
ATTN: Code 2027
Washington 25, D. C.   1

Chief, U. S. Army Security Agency
Arlington Hall Station
Arlington 12, Virginia   2

Deputy President
U. S. Army Security Agency Board
Arlington Hall Station
Arlington 12, Virginia   .   1

Commanding General
U. S. Army Electronics Research and
  Development Activity
ATTN: Technical Library
Fort Hauchuca, Arizona   -   1

Commander, Armed Services Technical
  Information Agency
ATTN: TISIA
Arlington Hall Station
Arlington 12, Virginia   10

Commanding Officer
U. S. Army Electronics Research and
  Development Laboratory
ATTN: SELRA/LNR
Fort Monmouth, New Jersey   1

Commanding General
U. S. Army Materiel Command
ATTN: R&D Directorate
Washington 25, D. C.   1

U. S. Navy Electronics Liaison Office
U. S. Army Electronics Research and
  Development Laboratory
Fort Monmouth, New Jersey   1

Commanding Officer
U. S. Army Electronics Research and
  Development Laboratory
ATTN: Logistics Division
Fort Monmouth, New Jersey   3

Commanding Officer
U. S. Army Electronics Research and
  Development Laboratory
ATTN: Director of Research
Fort Monmouth, New Jersey   1

Commanding Officer
U. S. Army Electronics Research and
  Development Laboratory
ATTN: Technical Information Division
Fort Monmouth, New Jersey   3

Commanding Officer
U. S. Army Electronics Research and
  Development Laboratory
ATTN: SELRA/NPT
Fort Monmouth, New Jersey   5

Commanding Officer
U. S. Army Electronics Materiel Support Agency
ATTN: SEIMS-ADJ
Fort Monmouth, New Jersey   1

National Bureau of Standards
ATTN: Library
Washington, D. C.   1

Commanding General
U. S. Army Combat Developments Command
ATTN: CDCMR-E
Fort Belvoir, Virginia   1

Commanding Officer
U. S. Army Communications-Electronics
  Combat Developments Agency
Fort Huachuca, Arizona   1

Director, Fort Monmouth Office
U. S. Army Communications-Electronics
  Combat Developments Agency
Building 410
Fort Monmouth, New Jersey   1

This contract is supervised by Mr. Jack Unger, Data Transducer
Branch, Data Processing Facilities Division, Communications De-
partment, U. S. Army Electronics Research and Development
Laboratory, Fort Monmouth, New Jersey, Telephone Area Code
201-535-2170.